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## Energy and Process Optimization and Benchmarking of Army Industrial Processes

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# **Energy and Process Optimization and Benchmarking of Army Industrial Processes**

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**Abstract:** Energy and process optimization studies were conducted at selected Army Arsenals and Depots ( Rock Island Arsenals; Corpus Christi, Tobyhanna, and Sierra Army Depots) to compare/benchmark energy use among these facilities and against private sector manufacturing facilities; and to identify energy conservation, process, and environmental opportunities that can improve the installations' competitive positions. The results were evaluated to determine which processes were efficient, and those that could improve. Four processes were identified as suitable for benchmarking: metal casting, metal finishing, painting, and heat treat. The metal casting operation at Rock Island Arsenal was found to be one of the most efficient of the 59 foundries surveyed. The remaining three Arsenal and Depot operations were found comparable with and in some areas more advanced than their private industry counterparts. By analyzing strengths and weakness, these benchmarks help installations to achieve greater energy efficiency by continuous process improvement. The report covers basic energy consuming systems at most facilities and details energy saving measures that can reduce energy use and increase operational performance. This work can be used by energy and production managers at other DOD installations to optimize production processes performance and reduce their energy use.

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## Preface

This study was conducted for the U.S. Army Corps of Engineers (HQUSACE) under project 0602784AT45, “Industrial Activities Readiness,” Work Unit CFE-IAR, “Industrial Energy Optimization Technology.” This is also a part of the IEA-ECBCS (International Energy Agency – Energy Conservation in Buildings and Community Systems) Annex 46 “Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo).” Technical monitors were Philip Columbus, Office of the Assistant Chief of Staff, Installation Management (OACSIM) and Paul Volkman, Installation Management Agency (HQIMA).

The parts of specific studies at different sites were conducted with contributions from participating installations: Rock Island Arsenal (RIA), under MIPR No. 4H13LRG040, for which the technical monitor was David Osborn, Energy Manager, RIA; Corpus Christie Army Depot (CCAD), under MIPR No. 5L32000010, for which the technical monitor was Shawn Smith, Energy Manager, CCAD; Sierra Army Depot (SIAD), under MIPR No. 4LFA04732B, for which the technical monitor was Robert Gee, Energy Manager, SIAD; Tobyhanna Army Depot (TYAD), under MIPR No. 4L3AB00192, for which the technical monitor was John Billack, Electrical Engineer, TYAD.

The work was managed and executed by the Energy Branch (CF-E) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL principle investigators were Dr. Alexander Zhivov and Dr. Mike Lin. Major contributors to the study were Dr. William Worek, Michael Chimack, Robert Miller, and Andrew Sheaffer. Noel Corral and Jonathan Aardsma are associated with the Energy Resources Center (ERC) of the University of Illinois at Chicago (UIC). Alfred Woody associated with Ventilation/Energy Applications, PLLC. Special thanks are owed to the support of the Department of Energy Office of Industrial Technologies (DOEOIT), to the Federal Energy Management Program, to Gary Gates, Energy Program Manager, Southwest Division, Naval Facilities Engineering Command and to Lars Fritz, Bruce Martin and Steven Barnkow from Plymovent Corp. UIC was partially funded under subcontract with Oak Ridge National Laboratory by the Federal Energy Management Program



(FEMP) Industrial Facilities Initiative. Additional information on FEMP's Industrial Facilities Initiative (and other FEMP Services) is available through Michaela Martin, Oak Ridge National Laboratory, tel. (865) 574-8688, or Alison Thomas, DOE Program Leader, tel. (202) 586-2099.

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CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander of ERDC is COL Richard B. Jenkins, and the Director of ERDC is Dr. James R. Houston.

## Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
British thermal units (International Table)	1,055.056	joules
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
foot-pounds force	1.355818	joules
gallons (U.S. liquid)	3.785412 E-03	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
inch-pounds (force)	0.1129848	Newton meters
miles (U.S. statute)	1,609.347	meters
ounces (mass)	0.02834952	kilograms
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters

# **1 Introduction**

## **1.1 Background**

The Department of Defense (DOD) is the largest energy consumer in the United States; it spends nearly \$3 billion dollars a year on energy. The Department of the Army, under DOD, is one of the largest consumers of energy within the Federal government. In fiscal year (FY) 2003, the Army spent \$769 million for 81 trillion BTUs of energy. This represents 40 percent of DOD and nearly 6 percent of Federal facility use.\*

The U.S. Army manages a large industrial base consisting in part of 14 government-owned plants that manufacture and repair ammunition and two arsenals that manufacture and repair ordinance materiel such as gun tubes, gun mounts, other weapon-related items, and repairs and upgrades to Army vehicles. In addition, the Army has numerous tactical equipment maintenance facilities (TEMFs) with different vehicle servicing and repair operations.

Some of these facilities recently have been upgraded and now have world class manufacturing capabilities. Still, many of their mechanical, energy, and environmental systems are near the end of their useful life. Most of these systems were likely designed with little consideration for energy conservation, security, or reliability. Too often, processes and supporting systems have been designed to meet theoretical maximums in demand due to the relatively low cost of meeting that demand in the past. This is a natural consequence of the inherent “peak and valley” use of Army manufacturing and repair facilities through periods of war and peace. In addition to periodic fluctuations in facility demands, increased utilities costs warrants a closer look at manufacturing processes, and at supporting energy systems and the industrial buildings that house these processes/systems.

Researchers from the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) and expert consultants have been supporting

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\* D. Williams, FY2003 *DoD Energy Management Data Report*. 2003. Washington DC: Headquarters, Department of the Army (HQDA).

the Army's effort to maintain mission readiness, to improve process efficiency, and to reduce energy consumption and operating costs by conducting energy and process optimization studies at selected industrial facilities (e.g., Rock Island Arsenal, Corpus Christie AD, Tobyhanna AD, Sierra AD, and the Naval Aviation Depot, San Diego). This study was undertaken to fill the need to compare/benchmark energy intensities in these facilities among each other and against similar private sector manufacturing facilities; to identify energy, process, and environmental opportunities that could significantly improve the installations' mission readiness and competitive positions.

## **1.2 Objectives**

The objectives of this work were to:

1. Introduce the methodology developed by ERDC-CERL for process energy optimization assessments,\* demonstrate it through showcase assessments at selected Army Depots and Arsenal, and identify and summarize energy conservation, process and environmental opportunities that can significantly improve Army installation mission readiness and competitive position.
2. Compare and benchmark industrial process energy intensities in these facilities among each other and against similar private sector manufacturing facilities to identify opportunities to improve energy and process efficiencies, and to reduce the environmental impacts of Army industrial activities.

## **1.3 Scope**

This work focuses on implementing an energy optimization assessment methodology and energy utilization benchmarks for four Army industrial processes: (1) metal casting, (2) metal finishing, (3) painting, and (4) heat treat. The work also addresses basic energy consuming systems present at most facilities and associated energy saving measures that can reduce energy use and increase operational performance. Measurements and information for both the primary energy systems and supporting systems were used to accurately benchmark these processes. For example, measurement

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\* Alexander Zhivov et al. *Energy and Process Assessment Protocol for Industrial Buildings*. 2006. Draft Tech Report. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).

of a primary system might be to directly determine the kilowatts-hour (kWh) used by the furnace in a melt during a metal casting. Measurement of a supporting system during the metal casting operation would be to record the energy used by the heating, ventilating, and air conditioning (HVAC) system as it worked to clean the air of heat and fumes.

#### **1.4 Mode of Technology Transfer**

The benchmark information resulting from this work and the associated energy optimization methodology will be disseminated to energy and production managers at other DOD installations through workshops, presentations, and professional industrial energy technology conferences. This report will also be made accessible through the World Wide Web (WWW) through URL:

<http://www.cecer.army.mil>

## **2 Energy and Process Optimization Studies**

### **2.1 Methodology**

During the past few years, ERDC-CERL has led energy and process optimization initiatives to help Department of Defense (DOD) installations meet energy efficiency and environmental compliance requirements and to create an improved work environment through “Energy and Process Optimization Assessments” at Army manufacturing and repair facilities. The ERDC-CERL developed “Energy and Process Optimization Protocol” has been tested and successfully applied to numerous energy assessments at Army Material Command (AMC) Arsenals, Depots, and Army Installations. This effort recently incorporated international expert experiences into the protocol and has been used to conduct energy assessments at non-industrial facilities with the participation and leadership of the International Energy Agency Energy Conservation in Buildings and Community Systems (IEA ECBCS) Program Annex 46 “Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo).” This effort was sponsored by Installations Management Agency (IMA) and Office of the Assistant Chief of Staff, Installation Management (OACSIM).

The Energy Assessment Protocol is based on an analysis of the information available from industry literature, training materials, documented and undocumented practical experiences of contributors, and successful show-case energy assessments conducted by a diverse team of experts at U.S. Army facilities. The protocol is geared to assist the following target groups of users:

- facility Energy Managers and in-house energy assessment groups
- companies providing energy assessment
- universities conducting energy assessment
- energy service performance contractors.

The protocol addresses organizational capabilities (both technical and nontechnical) required to successfully assess and identify energy and other operating costs reduction measures—without adversely impacting indoor

air quality, product quality (in the case of manufacturing or repair facilities), safety, or morale.

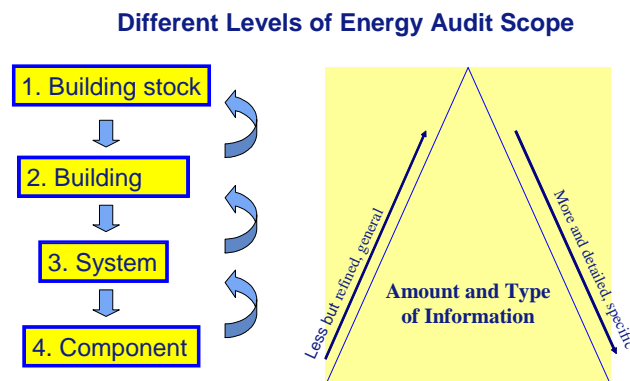
A critical element for energy assessment is the capability to apply a “holistic” approach to the energy sources and sinks in the audited target (installation, building, system, or their elements). The process outlined in the protocol identifies resource consuming activities and wasteful practices, prioritizes conservation opportunities, implements best practices, and guides investment in resource-conserving technology upgrades. The protocol addresses several different scopes (building stock, individual building, system, and component; cf. Figure 1), and levels of assessment:

*Energy conservation opportunities analysis.* This involves no instrumentation using basic analysis to generate a list of top energy saving ideas (Level 1).

*Energy optimization analysis geared toward funds appropriation.* This calculates savings and uses partial instrumentation with cursory analysis (Level 2).

*Detailed engineering analysis with implementation, measurement and verification (M&V).* This includes performance measurement and verification assessment, and a fully instrumented diagnostic audit (Level 3).

The holistic approach suggested by the protocol includes the analysis of opportunities related to the energy generation process and distribution systems, building envelope, lighting, internal loads, HVAC and other mechanical and energy systems (Figures 2 and 3), process energy flow (Figure 4), and the identification of existing saving potentials and development of recommendations for effective energy use.

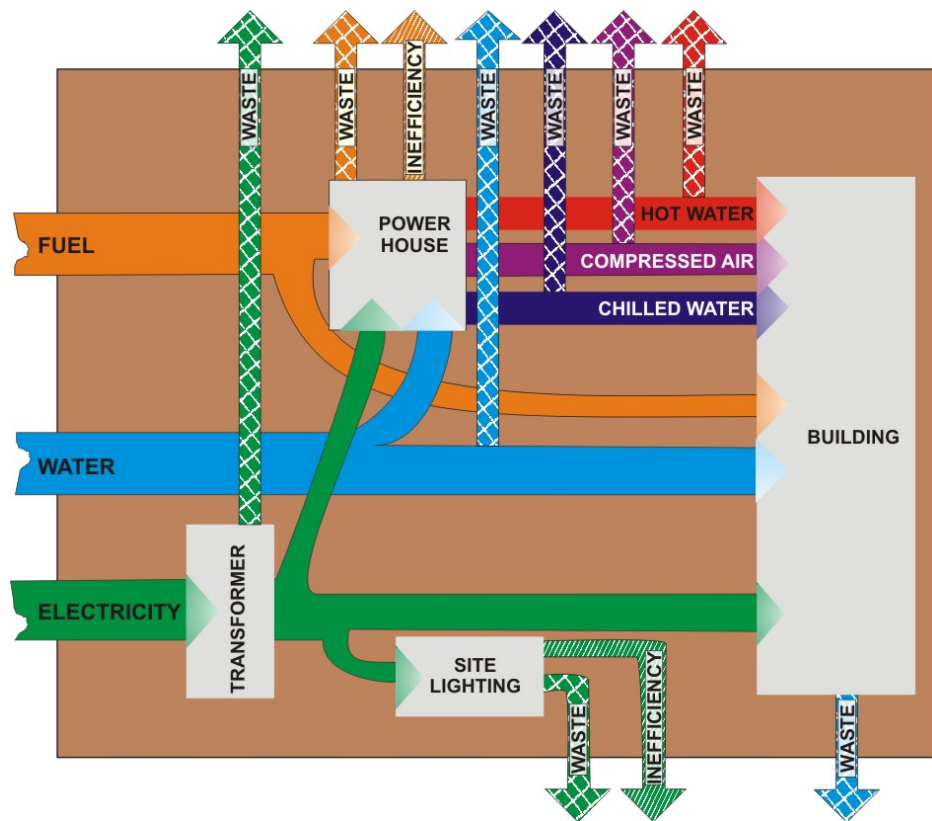


**Figure 1. Levels of energy audit scope.**

It is important to carefully examine both the supply and demand sides to identify waste and inefficiencies (Figures 2, 3, and 4). The assessment scope and depth may vary. The principles described in the protocol can be used to assess industrial buildings with such manufacturing or maintenance processes as:

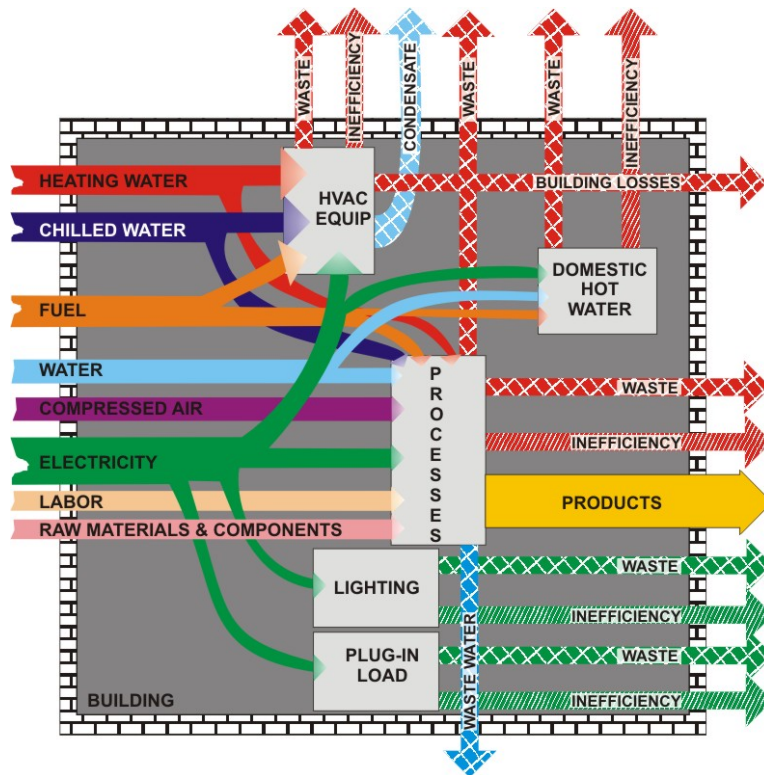
- foundries
- welding shops
- painting, paint stripping
- plating
- parts cleaning
- metal working
- heat treatment
- wood working
- loading, assembly and packing of munitions
- controls/electronics testing and repair.
- vehicle maintenance, including dynamometer testing cells.

The protocol can be also used to guide the assessment of buildings with similar processes or to perform partial energy assessment of other industrial buildings addressing the building envelope, HVAC systems, compressed air, heat supply systems, etc.

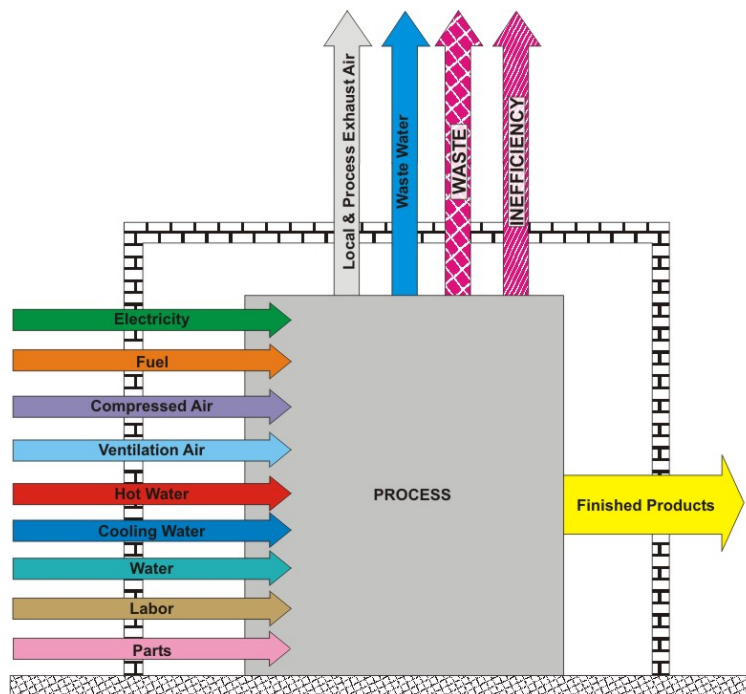


**Figure 2. Example of Sankey diagram of energy use, waste, and inefficiencies for Army installation.**





**Figure 3. Example of Sankey diagram of energy use, waste, and inefficiency for a building with production process.**



**Figure 4. Industrial process energy flow.**

## 2.2 Summary of Process Energy Optimization Assessments

During 2004 and 2005, ERDC-CERL developed and applied the Energy Assessment Protocol to several showcase Process and Energy Optimization Assessments at several Army facilities with manufacturing operations (Figure 5). The following reports document the Energy and Process Optimization Assessments at each of the Army Arsenals/Depots.

### 2.2.1 Rock Island Arsenal Phase I Report.

Mike C.J. Lin, Alexander M. Zhivov, Veera M. Boddu, David Osborn, Walter P. Smith, Curt Bjork, Michael J. Chimack and Robert A. Miller. *Process and Energy Optimization Assessment: Rock Island Arsenal, IL*. September 2004. ERDC-CERL TR-04-17. Engineer Research and Development Center, Champaign, IL: Construction Engineering Research Laboratory (ERDC-CERL). Available through URL:

[http://www.cecer.army.mil/techreports/erdc-cerl\\_tr-04-17/erdc-cerl\\_tr-04-17.pdf](http://www.cecer.army.mil/techreports/erdc-cerl_tr-04-17/erdc-cerl_tr-04-17.pdf)

### 2.2.2 Rock Island Arsenal Phase II Report.

Mike C.J. Lin, Alexander M. Zhivov, David M. Underwood, David I. Osborn, Alfred Woody, Walter P. Smith, Curt Bjork, Michael J. Chimack, and Robert A. Miller. *Process and Energy Optimization Assessment Level II Analysis: Rock Island Arsenal, IL*. August 2005. ERDC-CERL TR-05-15. Champaign, IL: ERDC-CERL. Available through URL:

[http://www.cecer.army.mil/techreports/erdc-cerl\\_tr-05-15/erdc-cerl\\_tr-05-15.pdf](http://www.cecer.army.mil/techreports/erdc-cerl_tr-05-15/erdc-cerl_tr-05-15.pdf)

### 2.2.3 Sierra Army Depot Phase I Report.

Mike C.J. Lin, Alexander M. Zhivov, Alfred Woody, Michael J. Chimack, and Robert A. Miller. *Process and Energy Optimization Assessment: Sierra Army Depot, CA*. August 2005. ERDC-CERL TR-05-17. Champaign, IL: ERDC-CERL. Available through URL:

[http://www.cecer.army.mil/techreports/erdc-cerl\\_tr-05-17/erdc-cerl\\_tr-05-17.pdf](http://www.cecer.army.mil/techreports/erdc-cerl_tr-05-17/erdc-cerl_tr-05-17.pdf)

### 2.2.4 Tobyhanna Army Depot Phase I Report.

Mike C.J. Lin, Alexander M. Zhivov, Alfred Woody, Curt Bjork, Walter P. Smith, Michael J. Chimack, and Robert A. Miller. *Process and Energy Optimization Assessment: Tobyhanna Army Depot, PA*. April 2006. ERDC-CERL TR-06-11. Champaign, IL: ERDC-CERL. Available through URL:

[http://www.cecer.army.mil/techreports/erdc-cerl\\_tr-06-11/erdc-cerl\\_tr-06-11.pdf](http://www.cecer.army.mil/techreports/erdc-cerl_tr-06-11/erdc-cerl_tr-06-11.pdf)

Table 1 lists some representative energy conservation measures (ECMs) identified at those Army installations, by category, along with respective information on investments required to implement each ECM, associated savings, and calculated simple payback period. Implementation of the 47 ECMs listed in Table 1 will reduce energy and operating costs by \$6.75M/yr, will yield an average simple payback of 1.5 years, and will im-

prove the working and living environment. The following Chapter gives a detailed description of some of these ECMs.



**Figure 5. Army facilities that participated in showcase Process and Energy Optimization Assessments.**

**Table 1. Energy conservation measures found at four Army arsenals/depots.**

Category	Base	Description	Investment (k\$)	Savings (k\$/yr)	Payback (yr)
Envelope	TYAD	Use cool roofs	0	6.8	0
	RIA	Improve B-220 working conditions and IAQ	273.2	61.6	4.43
	RIA	Install high-speed doors where necessary	64	43.1	1.48
	SIAD	Install door in north wall in Building 672	200	41	5
HVAC	CCAD	Air conditioning entire Building 8	500	357.5	1.4
	CCAD	Spot cooling at work stations	2370	2958	0.8
	TYAD	Reduce heating in five warehouses	100	210	0.5
	TYAD	Improve radiant heater controls	3.5	2.1	1.7
	TYAD	Improve controls of heating and ventilation	20	8	2.5
	TYAD	Improve temperature control and H&V	10	4	2.5
	RIA	Install on/off dampers in B-220 supply air ducts	6	2.5	2.4
	RIA	Perform further energy savings measures	2.5	2.2	1.19
	SIAD	Building 210 evaporative cooling system	90	40.4	2.2
	SIAD	Building 209 evaporative cooling system	90	25.4	3.5
	SIAD	Building 208 evaporative cooling system	90	65.7	1.4
	SIAD	Buildings 206/207 evaporative cooling system	71	32.9	2.2
	SIAD	Buildings 52 evaporative cooling system	27	18.9	1.4
Lighting	CCAD	CCAD lighting retrofit	2400	377.5	6.4
	RIA	Install task lamps in areas requiring additional lighting	72.1	58.9	1.22
	SIAD	Lighting retrofit in Building 52	57	6.1	9.3
	SIAD	Lighting retrofit in Building 672	58	10.3	5.6
Process	CCAD	Painting operations improvements	32	7.3	4.4
	CCAD	Install emission "elimination" cover on CR tank	370	256.8	1.5
	CCAD	Improved Plating Shop pressure control	110	63.6	1.7
	CCAD	Install exhaust systems for new equipment	0	0.9	0
	CCAD	Install demand based exhaust for welding	21.8	2.9	7.5
	TYAD	Replace existing controls in the Plating Shop	200	150	1.3
	TYAD	Recover heat from MAU steam vents in B-1E	100	345	0.3
	TYAD	Repair auto start/stop controls for four scrubbers	30	193	0.2
	TYAD	Install a variable frequency drive (VFD) on Scrubber PEF-3	20	23	0.8
	TYAD	Heat recovery from baking ovens in Paint Shop	20	8.2	2.4
	TYAD	Install VFDs on paint booth fan motors	140	27.6	5.1
	TYAD	Replace bag filters with roll filters	120	57.5	2.1
	RIA	Install EED on all chrome plating tanks	984.8	251.7	3.91
	RIA	Control airflows and steam heating	212	82.9	2.56

	RIA	Allow hot plating and rinse tanks to cool down	2.5	5.2	0.48
	RIA	Enclose drive-thru Paint Booth #1 in Bldg. 208	79.8	21	3.79
	RIA	Enclose drive-thru Paint Booth #2 in Bldg. 208	132.4	21.3	6.23
	RIA	B299 Paint Booth #4 improvements	145.9	114.7	1.27
	RIA	B229 Paint Booth #5 improvements	49.7	63.1	0.79
	RIA	Install improved ventilation system	15.9	35.5	0.45
	RIA	Replace critical foundry equipment in B-212 W	744.1	354	2.1
	SIAD	Building 210 Paint Shop vestibules	134.8	163.6	0.8
	SIAD	Building 209 welding operations improvements	46	58.2	0.8
	SIAD	Building 672 welding exhaust improvements	15.6	17.2	0.9
	SIAD	Remove fencing from Building 672	7.7	8.4	0.9
	SIAD	Use portable jib cranes in Building 672	120	86	1.4
		Total 47 ECMs	10359.3	6751.5	1.5

### **3 Typical Energy Conservation Measures Identified at Army Installations**

#### **3.1 Building Envelope**

It is generally true that implementing building envelope energy conservation measures do not result in quick payback for the investment, but if building is better sealed and insulated, the energy bill will be reduced.

##### **3.1.1 Improve Building Heating and Ventilation by Sealing Building Envelope**

Many industrial buildings over 50 years old are tall structures (over 30 ft high) with sky lights and large window areas on the walls to allow natural light to enter the space. These windows also have sections that can open for ventilation. Over time these glass windows become difficult to close, creating cold drafts in the winter. The cold drafts are worsened by the poor insulating quality of the single pane glass used in the skylights and window areas. The height of the buildings allows air in the space to stratify so that heated air quickly rises to the upper strata of the building. As a result, the work stations adjacent to the outer walls are cold in the winter, making employees uncomfortable and causing difficulties in machining of metal parts.

Figure 6 shows such a building at Rock Island Arsenal; this building has a north wall over 500 ft long and more than 50 ft high. Personnel assigned to production equipment adjacent to this wall complain of cold drafts in the winter. The fourteen steam unit heaters installed along this wall are largely ineffective. The manufacturing space also suffers for a lack of ventilation. Supply air is introduced on the south wall, approximately 60 ft from the north wall. Since an overhead crane operates in this area, the only location of air ducts is along the sidewalls.





**Figure 6. High bay manufacturing space at Rock Island Arsenal.**

To make this space more comfortable, the window area must be sealed to keep out outside air. This can be done using transparent panels that would fit just inside the windows in the wall opening. The existing windows would not be visibly changed from the outside, keeping the historical facade of the building intact. The panels would be sealed to the wall opening, only the lowest windows would open. The cost to install these new panels is \$229,000. The estimated cost savings of the new glazing is \$15,000, for a simple payback of over 15 years. Even though this project has a poor payback it should be done to make the workspace more usable and to provide reasonable working conditions.

### **3.1.2 Install Vestibules to Reduce Heating/Cooling Loads**

Industrial buildings have numerous doors that are open frequently to transport people and goods in and out of the building. Figures 7 and 8 show examples of large doors located close to the Plating and Sand Blasting shops at the Tobyhanna Army Depot. Open doors affect the pressure balance in the building. Most of the time, the space close to the doors or entrances suffers from a very large negative pressure. This results in a

strong cold inbound air stream in the winter and a very strong hot air stream in the summer. In both cases, this effects the energy consumption for building heating and cooling, workers comfort, and capture efficiency of local exhausts.

The proposed solution was to add walls that will create a vestibule close the door, and to install a second, fast interior door. Block the use of both doors simultaneously. (Only one door can be open at a time.) This solution will provide significant improvements in thermal comfort and energy use. Calculations made for similar case at Rock Island Arsenal showed a simple payback of approximately 3 years.



**Figure 7. Space for airlock, between plating and sand blasting shops.**



**Figure 8. Location for air lock.**

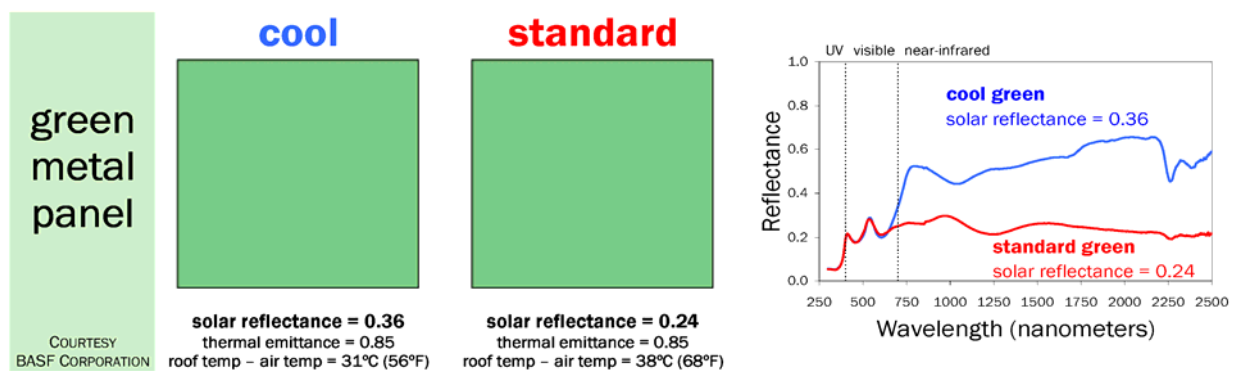
### **3.1.3 Use “Cool” Roofs**

A number of industrial buildings, e.g., at Tobyhanna Army Depot, are scheduled for roof replacement. Currently many roofs on industrial facilities are dark in color and coated with “absorption” paints, which absorb

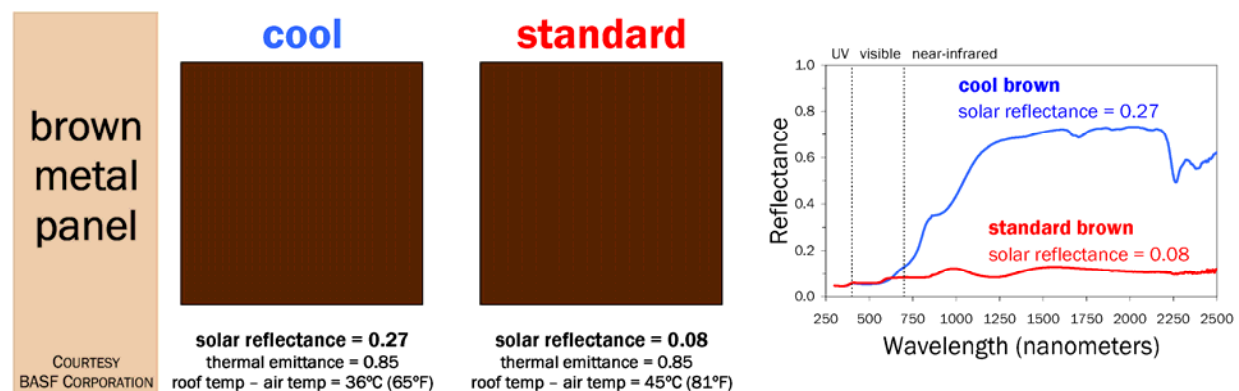


the sun's energy, and make the roof much hotter than the outdoor air temperature. If a reflective “cool” roof were used, much of the sun's energy will be reflected, keeping the roof cooler (Figure 9). Whenever replacing a building's roof it is recommended to use reflective paint of light color.

There is no cost savings in buildings with no air conditioning, but the “cool” roof will make them cooler and more comfortable to work in the summer. When the roof is over the air-conditioned building, “cool” roof results in energy savings with insignificant additional first costs.



**Cool green 12 °F cooler than standard green**



**Cool brown 16 °F cooler than standard brown**

**Figure 9. Characteristics of cool and standard metal roofs.**

### 3.2 Heating, Ventilation and Air Conditioning Systems

HVAC equipment provides a number of functions for an industrial facility or building; it moves air through the space to satisfy the needs of processes and to make the space safe for human occupancy. This equipment is often charged with maintaining the temperature of the space, and it accomplishes this by adding or removing heat from the ventilation air stream. The HVAC system also helps maintain the desired cleanliness of the space.

A number of considerations go into the proper design of the HVAC system. When considering the equipment selection for energy efficiency and lowest life cycle cost, both the operation at peak conditions and over average conditions must be analyzed. The outside weather conditions have a significant impact on these values. Generated internal heat and the requirement for large supply and exhaust air flows also greatly influence these values. Computer programs currently exist that help with this analysis. The factors that need to be considered are:

- desired indoor temperature and humidity
- desired ventilation rate
- building infiltration
- building shell insulation value
- internal heat release from ongoing activities inside
- outdoor climate
- the amount of glass allowing solar radiation to enter.

A building's HVAC system can be simple or complex. The complexity of the system may be increased to satisfy a need to maintain different space conditions inside the building, the desire to reduce energy use, or to improve system control. The simplest system has a air handling unit (AHU) that consists of a fan, filters, and a heating and cooling coil. The AHU delivers a single temperature of air to all the spaces it serves. This air can be either heated or cooled. Spaces requiring different air temperatures can be served by different AHUs. The temperature of the air can be modified in the distribution system, or the flow of air to that space can be varied. Many strategies may be applied to reduce energy use or improve comfort. Implementing these strategies adds components to the HVAC system, which must be maintained and kept in good working condition, otherwise system performance suffers and energy waste occurs. The American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE) Guide and Data

Handbook series\* provides an excellent discussion of the various HVAC components and how they function as well as components available for energy savings.

In an industrial facility, the HVAC system design is normally tailored for a specific process. The system's heating and cooling capability must consider the internal heat load from the industrial process before a final value can be determined. The amount of outside air handled by the AHU is selected to satisfy building and process exhaust systems plus the ventilation requirements of the space. Often when the function of a space changes, no modification is made to the HVAC system that services that space. The result can be an over-ventilated and over-heated space, which wastes energy. Many Army manufacturing or maintenance facilities do not have air conditioning in summer. High indoor air temperature and high humidity during summer months leads to reduced productivity of the work force. The effect of thermal environment on productivity has been studied by Dr. Bjarne Olesen of the Technical University of Denmark. Appendix A of this report includes some pertinent results of his studies and rest-work guidelines for hot-humid climates from the American Conference of Governmental Industrial Hygienists (ACGIH).

Ventilation systems remove an air stream from the building as one enters the building for replacement. Energy is used to temper the incoming air to suit conditions of the space or process. This energy can be greatly reduced by recovering heat from the exhaust air. Also, heat tends to rise in an open building, which makes the upper strata of the building warmer than the lower occupied zone. Heating energy can be saved by collecting the warmer ceiling air and redirecting it down to the floor.

Of all building energy-using systems, the HVAC system often uses the most energy. Electrical energy is required to operate the fans, which normally run most of the time. During the winter, a significant amount of heating energy is required. The cooling demand on electrical use can also be very significant. It is not unusual for the HVAC system to consume 20 to 30 percent of the total facility annual energy use.

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\* ASHRAE. 2003. *ASHRAE Handbook: HVAC Applications*. Atlanta, GA: ASHRAE Inc.  
ASHRAE. 2000. *2000 HVAC Systems and Equipment*. Atlanta, GA: ASHRAE Inc. (Both publications available through URL: [www.ashrae.org](http://www.ashrae.org)).

The following HVAC project descriptions summarize opportunities found to reduce energy consumption and improve conditions in the evaluated Army facilities.

### **3.2.1 Control Heating and Ventilation System in the Plating Shop**

The supply air system for the plating shop in one of the facilities consists of several AHUs, which operate continuously. The controls on the heating steam valves are inoperable; since the valves have no modulation control, they are either “on” or “off.” The plating tank exhaust system operates “as needed”; when no plating is being done, the exhaust operates either at half flow or totally off, i.e., if a plating line is not being used, its exhaust system would be turned off. This gives the plating shop a positive pressure most of the time, which allows plating airborne contaminants to migrate to adjacent spaces.

The solution to this situation is to install variable frequency drives on the AHU fan motors so the building air flow can be adjusted to match the current exhaust air flow. Also, control valves are required to maintain proper steam flow to avoid overheating. This project will save approximately 25 billion BTUs of heat and 550 kW of electrical power per year. The estimated implementation cost of the needed equipment is \$212,000; the annual cost savings are estimated to be \$152,000/yr; the simple payback occurs in 1 year.

### **3.2.2 Reduce Energy Use by Adding Dampers and Modifying Fan Speed of Air Handling Units**

Some of the spaces in this section of multistory building immediately adjacent to the high bay area are no longer being used, but the HVAC systems for these areas continue to operate at full capacity. Units that service only vacated spaces should be turned. Dampers should be installed in the air distribution ducts for units that still serve occupied spaces to reduce or stop air flow to unoccupied spaces. Also, fan speed should be reduced so the AHU handles the correct amount of air. The cost to make these changes is estimated to be \$44,000; the resulting energy savings would cost almost \$10,000; the simple payback would be 5 Years.

### **3.2.3 Improve Ventilation in New Machining Area by Modifying Air Handling Units**

New computer-operated machining equipment was placed in a room that had marginal ventilation and warmer than normal temperatures during the summer that caused unusual operator fatigue. Further investigation showed that the AHUs supporting this area were placed on the roof immediately above the work space. This roof had a dark surface that is slightly lower than the roofs of the adjacent spaces. The air intakes of these AHUs had duct connections that faced downwards. The net result of these factors was hot air being drawn from the dark roof into the AHUs, creating hotter than normal temperatures in the machining rooms, greatly affecting the operation of the machinery. There were also complaints that the noise from these units is quite loud, which can be explained by the short duct runs from the units to the air outlets.

To make the necessary improvements the air intakes need to be modified to bring in air that is 12 to 14 ft above the roof. Noise silencers should be placed in the air distribution ducts just down stream from the AHU. Air distribution will be enhanced by distributing the air in spaces between production equipment. The estimated cost for these modifications is \$17,000; savings will be realized in increased worker productivity.

### **3.2.4 Use Evaporative Cooling for Summer Heat Relief**

Most buildings with manufacturing operations have a heating and ventilating system to provide optimal working conditions for the employees. During the summer at many Army installations outside temperatures can often exceed 90 °F. People working indoors are subject to temperatures greater than those outdoors because of heat given off by processes, electric motors, lights, and other heat sources. Typically, indoor temperatures in an industrial plant can be 10 °F warmer than the outside temperature.

To avoid heat stress in an environment where the humidity and temperature reached a 85 °F wet bulb globe temperature,\* workers should be given working 15 minutes rest per hour. Based on DOD weather data (TM 5 785), Sierra Army Depot has 97 hours annually where it experiences tem-

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\* This value is the sum of 70 percent of the wet bulb temperature and 30 percent of the dry bulb temperature (in the absence of radiant heat).

peratures above 93 °F. This results in conditions where building spaces become too hot for productive work. Reductions in worker productivity of over 10 percent are not uncommon when temperatures exceed 90 °F. Figure 10 shows one of the work spaces, in this case a welding area, at SIAD.

Installation of an evaporative cooling system is proposed to reduce these summer temperatures. In the example building, two air-handling units with evaporative coolers would be located at each end of the building. These air handling units will discharge into a fabric duct to deliver the cool air through out the building. For winter operation, a duct will take warm air from the upper strata of the building and mix it with outside air for distribution. This will provide some building make-up air and help pressurize the building. This system will reduce cold drafts through walls openings.

The evaporative cooling system has air that passes through a wetted pad. As the air goes through the pad, it picks up water vapor, which increases its humidity while the temperature drops. In a dry region of the country like Sierra a temperature reduction of 20 °F could be obtained with this equipment. This cooler air will reduce space temperatures within the manufacturing facility to a few degrees lower than the outside, allowing workers to perform work more efficiently. Figure 11 shows an evaporative cooler already at SIAD. Figure 12 shows a portable air conditioning unit used to supply cool air to vehicles interior when they are being serviced.



**Figure 10. Typical manufacturing space at Sierra Army Depot.**



**Figure 11. Roll-around evaporative cooler now in use at Sierra Army Depot.**





**Figure 12. Use of portable air conditioning unit at Fort Stewart.**

In one representative building, 16 personnel working across two shifts are affected by the extreme heat. This particular operation at SIAD is working a significant amount of overtime and the avoidance of the loss in production during these hot days amounts to almost \$37,000 for the 16 people in this building. The cost of the evaporative cooling ventilation system is \$90,000. This system will help reduce the building's winter heating cost by \$2,300 since warm ceiling air will be redirected down to the worker level. There will be an additional electrical cost of \$1,000/yr. The total cost savings is \$37,000 for a simple payback of 2 years.

For the SIAD manufacturing area, a total of nine evaporative cooling ventilation systems are recommended at a total cost of \$368,000. The estimated annual savings is \$175,000 for a simple payback of 2 years.

### **3.2.5 Use Chilled Water Thermal Storage Tank**

At the Tobyhanna Army Depot industrial area the supply air system uses a number of air cooled refrigeration machines for cooling. These units are nearing the end of their useful lives and should be replaced with more efficient equipment available on the market. In one building, a chilled water system with a cooling capacity of 250 tons should be upgraded. To reduce the maintenance costs of this equipment and increase the energy effi-



ciency, a central chilled water system for the industrial area is proposed. The plan is to initially provide three 500-ton chillers that are cooled by cooling towers. These chillers will be piped to all air handling units that provide cooling. If the existing cooling unit has a direct expansion coil, a chilled water coil will need to be installed.

This installation should include a thermal storage tank that can be used to offset part of the total cooling load. It is estimated that a 350,000 gal tank will be required to store this water. A tank of this size will offset the installation of one 500-ton chiller system including its cooling tower, pumps and chiller. The thermal storage tank is estimated to be approximately 40 ft high and 38 ft in diameter. A place near the chiller building will need to be identified for locating the thermal storage tank.

A thermal storage tank will provide savings by generating chilled water during periods of low electrical demand, and by allowing chillers to operate at peak efficiency during periods with low cooling loads. Since TYAD pays no electrical demand charges, there are no cost savings associated with offsetting electrical demand by this project. There are spaces at TYAD that require year-round cooling and the chiller would need to operate at partial load to satisfy this demand. It is estimated this load is present approximately 5,000 hrs/yr during the non cooling seasons. It is also estimated that a chiller with this load operates at 80 percent of the efficiency of peak load. The estimated average load during this time is 20 percent of the chiller capacity or 100 tons. This efficiency improvement will save 60,000 kWh/yr, returning \$3,400 in annual savings.

The cost of a 350,000 gal insulated thermal storage tank is \$350,000. To this is added \$100,000 for piping, valves, and controls for a total cost of \$450,000. The tank will replace the need for a 500-ton chiller, cooling tower and associated piping, pumps, and controls the cost of which would be \$550,000. There is a net savings of approximately \$100,000 in the cost of constructing the chilled water system, so the savings are realized immediately.

### **3.2.6 Improve HVAC System Controls**

In a vehicle wash area there is a radiant heating installation that is controlled by two thermostats placed adjacent to each other. The present tem-

perature was measured to be 79 °F on the floor, 77 °F in the room and 88 °F at the ceiling. A new temperature controller should be installed and the temperature setpoint should be reduced to 68 °F. This controller should be set up in such a way as to control the operation of the radiant heaters so they work together. The new controller will cost \$3,500 to install and will generate an estimated heating savings of \$2,100/yr, resulting in a simple payback of 2 years.

Another building houses a wood shop and areas for box and carton fabrication and storage, and for trailer and generator repair. The heating system is a combination of unit heaters and heating and ventilation systems. The temperature in this space is kept between 70 and 75 °F. In one space a door is partly open so the area does not get too hot. To improve the temperature control, new temperature sensors should be installed in each of these spaces and the heating systems modified so they are controlled by these sensors. The estimated cost of these controls is \$20,000; they will provide an estimated \$8,000 in heating energy savings per year. The resulting simple payback is 3 years

In a Tactical Equipment Repair facility the heating systems are also overheating the building. Space temperatures were measured at 77 and 79 °F within the building. One space had a partially open truck door to reduce the temperature. Several heating and ventilating units are used, some with heat recovery equipment. There are also unit heaters. All this equipment should be recalibrated, or new temperature controls should be installed. This will cost an estimated \$10,000. The estimated energy cost savings is \$4,000; Simple payback will occur in 3 years.

### **3.3 Compressed Air Systems**

Compressed air (CA) is used as a source of power for tools, industrial processes, and equipment. It is often considered as a fourth utility, after electricity, natural gas, and water. In most plants/shops, CA is centrally generated and distributed to all users through a pipe network. Although CA systems are a very convenient power source, they are expensive to operate. Nearly all industrial plants can realize from 25 to 40 percent savings on the power costs for the CA system without additional capital expenditures through improved CA system management, which can save energy,

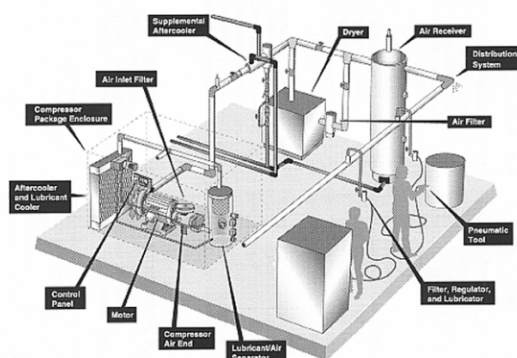
decrease down time, reduce maintenance, increase productivity, and improve quality.

### 3.3.1 Implement a Compressed Air Management Program

Compressed air is one of the most expensive utilities in facilities today. By implementing a compressed air management program, leaks and other associated losses can be identified and fixed, resulting in high cost savings and short paybacks for most facilities. Figure 13 schematically shows a simple compressed air system.

Despite the high energy consumption of a compressed air system, measures can be taken to avoid additional costs. Every facility that uses compressed air should implement an air management program. The first step is to identify, tag, and repair leaks. (This is more fully described in the following section.) After repairing the leaks, facilities should seek the help of a compressed air specialist to re-evaluate the compressed air demand of the facility and adjust the pressure accordingly.

An aggressive demand-side management program can eliminate 10 to 15 percent of unnecessary compressed air use. Additionally, oversized and inefficient air compressors can be replaced with smaller, higher efficiency units. Other equipment, including the air dryers, control valves, piping, and control valves can be repaired, upgraded, or replaced to improve system efficiency. Finally, a central information and computer management system can be installed to allow for system automation. A compressed air management program can be implemented at any facility that uses compressed air.



**Figure 13. Compressed air system.**

The costs associated with a compressed air management program are dependent on the compressed air system. Therefore, it is difficult to establish a general cost. However, many industrial facilities that have implemented compressed air management programs have experienced immediate pay-back on air leaks and a range of one to 3 years for equipment upgrades and implementation of controls.

### **3.3.2 Implement a Compressed Air Leak Management Program**

Compressed air leaks are a significant source of wasted energy, often wasting as much as 20 to 30 percent of the compressor's output. Compressed air leaks contribute to problems with system operations by fluctuating the system pressure (causing pneumatic equipment to function less efficiently), the need for an oversized compressor, and an increased maintenance program. The Department of Energy recommends that a leak management program should include leak identification and tagging, tracking, repair, verification, and employee involvement. Ultrasonic acoustic detectors can be used to recognize high frequency hissing sounds associated with compressed air leaks. Once the leaks are repaired, the compressed air controls are reconfigured to match the reduced demand. Any facility with compressed air will almost certainly have air leaks that can be repaired. A leak management program can reduce leaks to less than 10 percent of compressor output.

A compressed air leak management program can be contracted out, or performed by in-house labor. This would require the facility to purchase an ultrasonic acoustic detector. As detecting and repairing compressed air leaks is a maintenance function, it can be argued that the only cost is that of purchasing a leak detector, which can cost anywhere between \$1,000 and \$6,000, depending on the model and capabilities desired.

### **3.3.3 Reduce Compressed Air System Pressure (Controls)**

Compressed air pressure should be reduced incrementally until the lowest possible tool and equipment pressure is achieved. The challenge in controlling air compressors is to match their throughput to the process requirements while keeping total flow high enough to prevent surge. This goal is often complicated by the variable nature of the minimum safe flow rate and the configuration of the compressors.

Increases in air pressure setpoints may have been made to overcome excessive air leaks or because new compressed air equipment was installed using undersized distribution piping. Considering that most compressed-air tools and equipment can be operated satisfactorily with a 90 psig pressure setpoint and that the average well-designed compressed-air distribution system will experience a pressure drop of approximately 10 psig at the farthest distribution point, the setpoint for the compressors should be 100 psig. It is recommended that all adjustments to compressor setpoints be done incrementally and that the cause of an excessive pressure setpoint be identified. Pressure reductions can be applied to almost any compressed air system. For every 2 psig that pressure is reduced, the required brake power (bhp) will be reduced by 1 percent. There are no installed costs for reducing compressed air pressure. Pressure can be reduced with a simple adjustment of the controls.

#### **3.3.4 Reduce Inappropriate Uses of Compressed Air**

Inappropriate uses of compressed air include any application that can be done more effectively or more efficiently by a method other than compressed air. Since compressed air generation is one of the most expensive utilities, inappropriate uses should be identified to reduce electrical energy consumption of the compressed air systems.

Inappropriate uses of compressed air include: personal cooling, cleaning, drying, and process cooling. In addition, there are many types of equipment that should be operated by some other means of energy. Some of these include: vacuum generators, air motor-driven mixers, and air operated diaphragm pumps. Since compressed air generation is so expensive, electrical energy should be used to operate the equipment as opposed to compressed air. Inappropriate uses of compressed air can be found in any facility that uses compressed air. These uses should be reduced or eliminated to reduce operating costs of the compressed air system.

The costs associated with reducing inappropriate uses of compressed air are varied. Some are changes in operations and maintenance with no implementation cost, while others require the purchase and installation of equipment ranging in cost from \$50 to several thousand dollars, depending on the application.

### **3.3.5 Air Compressor Heat Recovery**

As much as 80 percent of the electrical energy used by an industrial air compressor is converted into heat. A properly designed heat recovery unit can recover anywhere from 50 to 90 percent of this available thermal energy to heat air or water. Approximately 50,000 BTUs/hr is available per 100 cfm of compressor capacity when running at full load. Typical uses for recovered heat include supplemental space heating, industrial process heating, water heating, makeup air heating, and boiler makeup water preheating. Recoverable heat from a compressed air system is not normally hot enough to be used to produce steam directly. Heat recovery systems are available for both air-to-air and air-to-water cooled compressors.

There are no fumes associated with recovering heat from air compressors. Air expelled from air compressors to cool the units is filtered before leaving the compressor housing, so there is little particulate matter that will be introduced as part of heating air. Caution should be applied because if the supply air for the compressor is not from the outside, and the recovered heat is used in another space, the static pressure in the cabinet can be decreased, reducing the efficiency of the compressor. If outside air is used, some return air may be required to avoid damaging the compressor with below-freezing air.

## **3.4 Motors**

### **3.4.1 Description**

Electric motors are required to power a wide range of equipment and devices. The loads on the motors can vary or be relatively constant. When selecting a motor it is best to match the motor size to the process load. A partially loaded motor operates at a lower efficiency than one fully loaded.

Motor efficiency ranges from 75 percent for a standard 1 horsepower (hp), three-phase induction motor operating at full load to 90 percent for a standard 50 hp motor. In 1992, the Energy Policy Act was passed that required most motors manufactured after October 1997 to meet higher efficiency standards. The operating efficiencies set for 1 and 50 horsepower motors are 82.5 and 93 percent, respectively. There are also premium efficiency motors available at extra cost whose efficiencies range from 85.5 to 94.13 percent for the same range of motors. Single phase motors are nor-

mally 5 to 10 percent lower in efficiency than similarly sized three phase motors. Another benefit of the higher efficiency motors is they run cooler and have longer service lives.

Electric motors have a limited life. When they burn out they typically can be repaired by rewinding to become operable again. A downside to this repair is a loss in efficiency. It is often more economical to replace a burnt out motor with a new premium efficiency motor than to rewind it. The reduction in cost to operate the premium efficiency motor will easily repay the purchase price over the service life of the motor.

### 3.4.2 Replace Standard Efficiency Motors

At Fort Stewart, there are numerous electric motors ranging in size from ½ to 25 hp that power fans, pumps, and air compressors. These motors are all standard efficiency units. It is recommended that these motors be replaced with premium efficiency motors when they fail and need replacement. Table 2 shows the annual savings and the additional cost of the premium motors. The resulting payback ranged from 2.9 to 6.2 years.

**Table 2. Motor replacement savings.**

Motor Size	Existing Efficiency (%)	Proposed Efficiency (%)	Energy Saved (kWh/yr)	Energy Cost Savings (\$/yr)	Total Cost Premium (\$)	Simple Payback (yrs)
25	88.5%	93.8%	3,146	\$169	\$823	4.9
3	81.5%	89.7%	1,213	\$65	\$189	2.9
1	80.5%	87.2%	526	\$37	\$229	6.2
1	75.1%	85.5%	4,885	\$29	\$136	4.7
Total	---	---	4,885	\$271	\$1,241	4.6

Figure 14 shows a large fan at one of the Arsenals. Normally, fans are operated at or near the full load rating of the drive motor for most hours of the year. A heavy, constant load that must be maintained for several thousand hours per year is a good candidate for installation of a premium efficiency motor.



**Figure 14. Electric motor operating a fan.**



**Figure 15. Electric motors driving pumps.**



Pumps are another application that may be a good candidate for installation of a premium efficiency motor. Pumps must move heavy liquid loads. If the loads are unvaryingly constant and the pumps operated constantly throughout the year, they may be particularly suited for a premium efficiency drive motor. If the loads are heavy and constant, but occur for short periods of time, a premium efficiency motor may not be the best choice. Figure 15 shows two pumps located a production area of one of the Depots.

### **3.5 Boilers and Steam Distribution Systems**

The DOD owns a large number of aging district heating systems, typically consisting of a central heat plant and a heat distribution system. The Army alone has approximately 1,100 central boilers and 1,900 miles of heat distribution piping. Replacement value for the Army systems is valued at \$5.3 billion. Many of these systems are nearing the end of their useful lives, incurring significant maintenance and repair costs to keep them operational. Typical system designs were developed when energy costs were low and when energy efficiency was not seen to be as important a factor as security and fuel independence. A number of measures can be taken to reduce the energy use of these systems and reduce costs.

#### **3.5.1 Automatic Steam Trap Monitoring**

Automatic steam trap monitoring systems can be used in boiler distribution systems to identify failed traps. Identifying and correcting failed traps will improve system performance and safety levels and increase process energy savings.

Automatic steam trap monitoring systems are typically remotely mounted. They continuously scan the steam trap sensors and indicate whether or not steam wastage or waterlogging occurs at any of the traps being monitored. “Wastage” implies that the trap is failed open or the steam is flowing through the steam trap. Waterlogging implies that the trap is failed closed or neither steam nor condensate is flowing through the steam trap. Waterlogging is dangerous because pressure can build up in the steam line before the steam trap. Pressure buildup can cause steam lines to rupture, resulting in a safety hazard.

When failed traps are identified through the use of an automatic steam trap monitoring system, productivity costs, steam raising costs, mainte-

nance costs, and emissions from the boiler plant can be reduced. Automatic steam trap monitoring systems can be installed in any boiler system that uses steam traps.

Automatic steam monitoring systems are conservatively estimated to provide a 5 percent reduction in energy costs. Up to 15 percent energy savings can be obtained by implementing a steam trap maintenance program in addition to the monitoring system. This program involves visual inspections of steam traps and their associated maintenances. The cost of an automatic steam trap monitoring system ranges depending of the amount of steam traps that need to be monitored. Costs are estimated to range from \$500 to \$1,500 dollars/unit, with an associated installation cost of \$1,500. Savings can range from several hundred to several thousand dollars per year for each steam trap, depending on the line pressure and how quickly the failure is caught. Payback of the investment cost can be realized in less than 2 years.

### **3.5.2 Improve Combustion Efficiency of Boilers**

Operating a boiler with an optimum amount of excess air will minimize heat loss up the stack and improve the combustion efficiency. On well-designed natural gas-fired systems, an excess air level of 10 percent is both optimum and attainable. Combustion efficiency is a measure of how effectively the heat content of a fuel is transferred into usable heat. The stack temperature and flue gas oxygen concentrations are primary indicators of combustion efficiency. The correct amount of excess air is determined from analyzing flue gas oxygen or carbon dioxide concentrations. Inadequate excess air results in unburned combustibles while too much excess air results in heat lost due to the increased flue gas flow, which results in a lowered overall boiler fuel-to-steam efficiency. Optimization of the combustion efficiency can be applied to any natural gas boiler. A rule of thumb is that boiler efficiency can be increased by 1 percent for each 15 percent reduction in excess air or 40°F reduction in stack temperature.

There is no cost associated with tuning a boiler using in-house maintenance personnel and available combustion analyzing equipment. Assuming that the facility wants to purchase its own equipment, the cost of a combustion analyzer can range from \$500 to \$2,000. The units are relatively simple to operate and most of the basic functions can be learned in

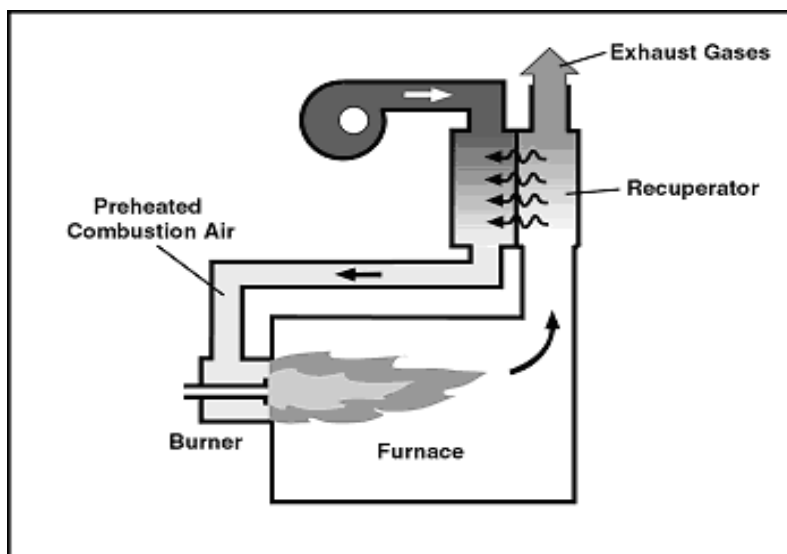
less than an hour. Assuming that the facility wants to use a private service, a boiler tuning can cost approximately \$2,000/unit. Depending on the boiler and the burners, boiler tuning should be done at least annually and possibly as often as four times per year. Depending on boiler operation and the rating of its burners, savings can range from several hundred to several thousand dollars/unit. Payback is usually less than 1 year.

### 3.5.3 Boiler Heat Recovery

Recovering waste heat from boiler flue gas and using economizers and recuperators to preheat feedwater and combustion air greatly increases a steam distribution system's efficiency. Figure 16 schematically illustrates the application of a recuperator.

Boiler flue gases are often rejected to the stack at temperatures more than 100 to 150 °F higher than the temperature of the generated steam. Generally, boiler efficiency can be increased by 1 percent for every 40 °F reduction in flue gas temperature by using a feedwater economizer. A feedwater economizer reduces steam boiler fuel requirements by transferring heat from the flue gas to incoming feedwater. A recuperator operates in a similar manner by recovering stack waste heat to preheat combustion air.

Figure 17 illustrates the application of a boiler stack economizer.



**Figure 16. Cut-away view of a recuperator.**

A feedwater economizer is appropriate when insufficient heat transfer surface exists within the boiler to remove combustion heat. Boilers that exceed 100 hp, operating at pressures exceeding 75 psig or above, and that are significantly loaded all year long are excellent candidates for an economizer retrofit. An economizer or recuperator can often reduce fuel requirements by 5 to 10 percent and pay for itself in less than 2 years.

### 3.5.4 Eliminate Steam Leaks

Steam leaks contribute to direct heat loss in a steam distribution system. The heat loss causes an increase in boiler load and makeup water consumption because additional steam needs to be produced to maintain the load requirements of the system. Figure 18 shows a steam leak found in one of the Depots. Eliminating steam leaks will save energy and improve operating efficiency of the boiler system. If leaks are ignored, they can cause a drop in the pressure of their respective systems, resulting in heat loss and reduced operating efficiency. Steam leaks can be found in any steam distribution system. They are typically found at valve stems, unions, pressure regulators, equipment connection flanges, and pipe joints.



**Figure 17. Cut-away view of a boiler stack economizer.**



**Figure 18. Large steam leak.**

The first step is to conduct a steam leak survey. Large steam leaks are visible, while ultrasonic detectors can identify smaller leaks. The leaks should then be tagged and fixed either by onsite personnel or by specialized service technicians. Eliminating leaks can improve production, increase condensate return, increase boiler efficiency and overall system efficiency resulting in energy savings.

A steam leak maintenance program can improve operating efficiency by 10 to 15 percent. If there has been no steam trap survey or maintenance program, upwards of 50 percent of a system's traps can be blowing live steam. If a survey is performed annually, this figure drops to approximately 25 percent. A biannual survey will reduce this even further, to less than 12 percent.

Ultrasonic leak detectors cost about \$1,300, while an average steam leak costs up to \$3,500 a year in lost steam production. The cost of a detector will be repaid in the savings made from fixing just one leak. Repair costs for the leaks themselves vary, but they are far less than the savings realized, providing simple paybacks that are usually realized in less than 1 year.

### **3.5.5 Insulate Steam Distribution Piping and Condensate Return Piping**

Uninsulated steam distribution and condensate return lines are a constant source of wasted energy. Insulation can typically reduce energy losses by 90 percent and produce proper steam pressure at end users. Any surface over 120°F should be insulated, including boiler surfaces, steam and condensate return piping, and fittings.

Damaged insulation should be repaired and/or replaced to avoid compromising the insulating value. Sources of moisture should be eliminated before insulation replacement. Causes of wet insulation include leaking valves, external pipe leaks, tube leaks, or leaks from adjacent equipment. After steam lines are insulated, changes in heat flows can influence other parts of the steam system.

## **3.6 Lighting**

Lighting consumes approximately 25 percent of a typical Army facility's energy. Since lighting uses high-cost electrical energy, it provides an at-

tractive target for energy conservation efforts. Illumination systems are also cheaper to retrofit and less complex than many other building systems such as central heating or cooling plants or building automated control systems. New lighting technologies offer opportunities to decrease energy use and improve the quality of lighting in a single step. Low risk, proven technologies can reduce lighting energy use by 50 to 75 percent.\*

Lighting can be improved in a number of areas at Army Arsenals, Depots and Facilities. One area common to all the assessed Army facilities is high-bay spaces. These spaces include hangars, large paint booths, repair spaces, warehouses, storage areas and machine shops. The light from a standard fluorescent tube or incandescent bulb is too diffuse to adequately light a surface at the distance required for high-bay applications. Therefore, high-bay lighting typically requires one of the following:

- metal halide high-intensity discharge (HID) lamps
- high-pressure sodium HID lamps
- high-output fluorescent (HOF) T5 lamps.

### **3.6.1 Replace High Intensity Discharge (HID) Lamps with High Output Fluorescent (HOF) Lamps**

Metal halide (MH) and high-pressure sodium (HPS) lamps have historically been the most commonly used lamps in high-bay applications, and these are the technologies that have been incorporated in most Army facilities to lesser or greater degree. High-output fluorescent (HOF) T-5 lamps should be considered when determining whether to retrofit MH or HPS lamps and fixtures.

Figure 19 shows an HID lighting application at Rock Island Arsenal. The lighting clearly does not provide sufficient illumination for the space. Figure 20 shows an industrial facility lit by HID lamps and ballasts.

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\* Elisabeth M. Jenicek, Christine Zimmer, and Aide Uzgir, *Energy-Efficient Lighting on U.S. Army Installations Lighting Retrofit Survey*. March 2001. ERDC/CERL TR-01-25/ADA391771. Champaign, IL: ERDC-CERL.



**Figure 19. HID lighting at Rock Island Arsenal.**



**Figure 20. Printing facility.**

Switching from HID lamps to HOF T5 fluorescent lamps is now a common strategy for increasing energy efficiency in high-bay lighting situations.

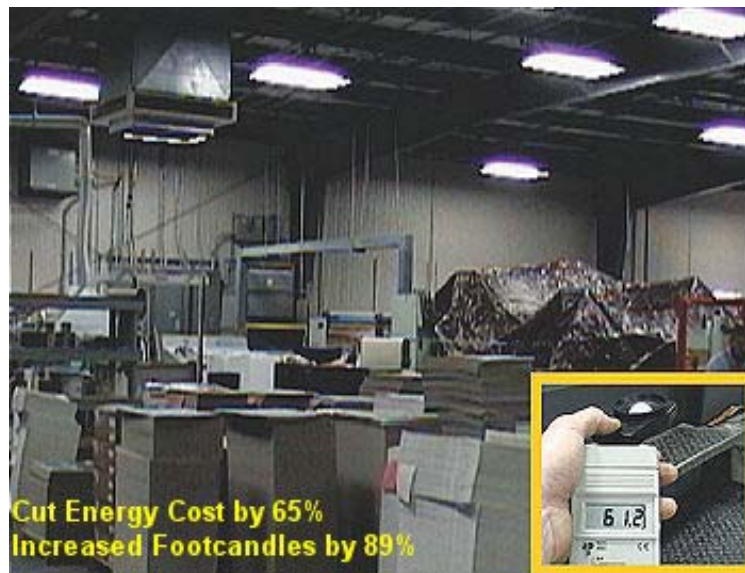
High-output T-5s:

- are capable of instant-on and instant re-strike
- can be used with energy-saving occupancy sensors
- can be adjusted through dimming (with a dimmable ballast)
- have lower average mercury content than metal halide HID lamps.



Figure 21 shows the same industrial facility lit by HOF lamps and ballasts. In both pictures, the lumen level is measured and displayed on a digital light meter.

As can be seen, the light levels have increased while energy use has decreased. Figure 22 shows a vehicle maintenance shop lit by HID lamps and ballasts. Figure 23 shows the same vehicle maintenance facility lit by HOF lamps and ballasts.



**Figure 21. Printing facility (after lighting retrofit).**



**Figure 22. Vehicle maintenance facility (before retrofit).**





**Figure 23. Vehicle maintenance facility (after retrofit).**

High-output fluorescent lamps have higher light output, better color, and longer life than HID lamps. Improved phosphors and ballasts allow fluorescent lamps to start at lower temperatures and to be switched on and off frequently without reducing lamp life. High-output fluorescent lamps can be used wherever high intensity discharge lamps are installed, with the exception of outdoor areas.

HOF lamps have the potential to consume approximately 50 percent less energy than HID lamps, offering significant savings:

- demand savings between 0.2 kW to 0.244 kW/fixture (45 percent to 53 percent demand savings/fixture)
- annual energy savings (without controls) of 650 kWh to 2,140 kWh/fixture
- annual energy savings (with controls) of 850 kWh to 2,700 kWh/fixture.

The cost to purchase and install a single HOF fixture ranges from \$400 to \$800, depending on purchase, labor, and other installation costs. HOF lamps have been available to consumers for about 10 years.

### **3.6.2 Install Lighting Tubes**

A renewable lighting solution is gaining in popularity as electricity costs continue to increase. Lighting tubes, also known as tubular skylights, cap-

ture sunlight and redirect it down a highly reflective shaft, then diffuse it throughout the interior space.

Figure 24 shows a portion of a garage lit by a combination of lighting tubes, a high-intensity discharge lamp (immediately behind beam just off of center), and a skylight (rectangle on right, behind beam).

Figure 25 shows an office space lit by a combination of lighting tubes and fluorescent lamps.

Finally, Figure 26 shows a warehouse lit exclusively by lighting tubes.



**Figure 24. Mixed lighting, including lighting tubes.**

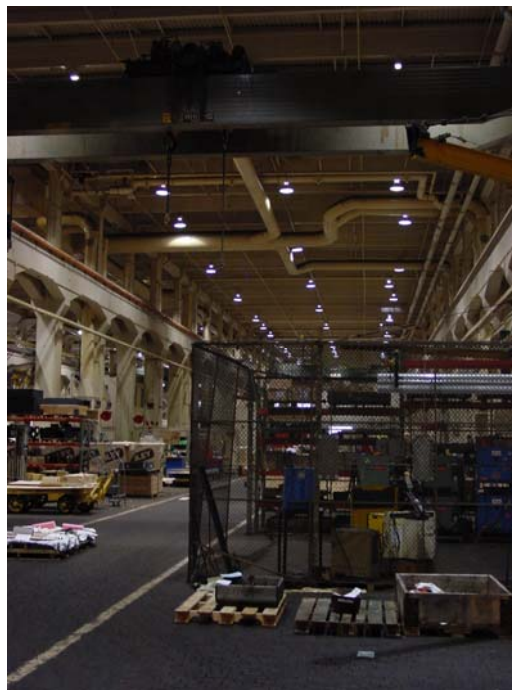


**Figure 25. Office lighting tubes.**



**Figure 26. Warehouse lighting tubes.**

Lighting tubes, either alone or supplemented by fluorescent and/or HID lighting, offer lighting and HVAC energy savings by supplementing or replacing daytime electric lighting with natural lighting. Lighting tubes can be installed in place of or as a supplement to lighting fixtures already in place. On cloudy days, the lighting fixtures can be used to provide additional lighting to illuminate the workspaces. Figure 27 shows a space within Rock Island Arsenal which, while well lit, would benefit from supplemental illumination.



**Figure 27. High-bay area in Rock Island Arsenal.**

Electric lighting, together with its affect on HVAC, accounts for a significant percentage of most facilities electric bills. Natural lighting can greatly reduce this electricity cost by displacing lighting systems currently in place and also by reducing the heat generated within a building that the HVAC system must condition. The U.S. Department of Energy's (DOE) Federal Energy Management Program reports that daylighting can significantly cut lighting energy use for lighting building interiors, sometimes by up to 75 or 80 percent.

Depending on the unit installed, purchase costs can be as high as \$1,500/assembly. Installation costs vary greatly due to roof type, type of installation, and labor costs.

### **3.6.3 Install Task/Spot Lighting at Work Places**

One component of an energy-efficient lighting system that is often overlooked is the use of task lighting. Use of task lighting can significantly reduce overall lighting demands by effectively putting the light where it is needed—on an individual's workstation or desk. Instead of attempting to generate all the light needed on the desktop from overhead fixtures, a system that uses task lighting can achieve desired lighting output at the work surface level more efficiently and with less power consumption.

Task lighting improves the quality of light by putting users in control of the direction and intensity of the light falling on their work areas. This flexibility is crucial to compensate for differences in vision between people. Older people need substantially more light to see than younger people. Even the visual capabilities of individuals of the same age can vary greatly.

Task lighting increases illumination above ambient levels at workstations. If the use of task lighting can allow occupants to shut-off or reduce overhead lighting, energy and cost savings can be achieved. Figure 28 shows a task lamp installed on an industrial grinder. Two kinds of task lighting exist: fixed and flexible arm models. The fixed models are typically fixed linear fluorescent (T-8 or older T-12) systems used in office and industrial settings. Desktop task lighting units are available with low wattage (less than 20 watts) compact fluorescent lamps or light emitting diodes. Figure 29 shows a workstation at Rock Island Arsenal with task lighting in addition to the overhead high bay lighting.



**Figure 28. Industrial task lamp.**



**Figure 29. Task lighting at workbench.**

Energy efficient applications of task lighting can reduce overall ambient lighting energy use from 1.5 to 1.0 W/sq ft. For a 10,000 sq ft space that operates 2,000 hrs/yr, this can result in savings of 10,000 kWh/yr. At a cost of \$0.05/kWh, this totals \$500/yr. For Army facilities that are several hundred thousand square feet in size that operate nearly year round, the savings can reach several thousand dollars per year. A task light can range in cost from \$15 to several hundred dollars, depending on the size and application.



#### **3.6.4 Replace Incandescent Lamps with Compact Fluorescent Lamps (CFLs)**

While considerably smaller than other lamps seen in Army facilities, standard incandescent light bulbs, used in many applications, use three to four times more electricity than compact fluorescent lamps (CFLs).

Compact fluorescent lamps are more energy efficient than incandescent lamps because the light output is produced in a different manner. In an incandescent bulb, light is produced by means of heating a filament, while in a compact fluorescent bulb, voltage is applied to a gas to produce ultraviolet light. The ultraviolet light then impacts the sulfur coating inside the bulb and produces visible light. Since the compact fluorescent bulb does not use heat for light output, it is more energy efficient than an incandescent bulb. Figure 30 shows a compact fluorescent lamp.

Compact fluorescent lamps provide as much light as incandescent lamps while using one quarter of the amount of power. Most compact fluorescent lamps require a ballast, making them slightly larger than incandescent lamps. In addition, compact fluorescent lamps output light from a linear source. This means that they produce light with less glare than an incandescent lamp, but cannot be directed as well as an incandescent lamp. Figure 31 shows an example of supplemental lighting provided by an incandescent lamp.



**Figure 30. Compact fluorescent lamp (CFL).**



**Figure 31. Incandescent task lamp at Sierra Army Depot.**

Compact fluorescent lamps can be used in any area where incandescent lamps are found. One drawback, however, is that compact fluorescent lamps are larger than incandescent lamps and may not always fit. Research needs to be done to identify whether or not a compact fluorescent bulb would fit into the selected application. In addition, compact fluorescent lamps are not particularly effective at producing spotlight type lighting because of their linear source output characteristic. They are most effective when used in area lighting applications.

Compact fluorescents are most cost effective and efficient in areas where lights are on for long periods of time. Paybacks are longer when compact fluorescents are not on for long periods of time.

The cost of compact fluorescent lamps range from \$5 to \$50 depending on the type of application. Since compact fluorescent lamps do not need to be changed as often, lamp replacement costs are greatly reduced in comparison to incandescent lamps.

### **3.6.5 Replace Incandescent or Fluorescent Exit Lamps with Light Emitting Diodes (LEDs)**

In one application, that of emergency exit signs, light emitting diodes (LEDs) can be used to replace both incandescent and fluorescent lamps. Light emitting diodes are semiconductor materials that emit light when an electrical current flows through them. LEDs are highly efficient because they use nearly 100 percent of their electricity and produce relatively no heat. Figure 32 shows a breakdown of the components of an LED.



**Figure 32. Light emitting diode cross-section.**

Light emitting diodes conserve energy because they require very low amperage to operate and produce relatively no heat. This results in a very high efficacy, or efficiency. Instead of a filament, LEDs use a small conductor chip that has an extremely long life as compared to incandescent and fluorescent lamps. While incandescent lamps can last up to 2,500 hours, some white emitting diodes can last up to 219,000 hours. Light emitting diodes are being adopted in a variety of applications in addition to exit lamps, including small area lighting and in task lighting.

Figure 33 shows an LED exit sign. The LEDs can be seen running horizontally near the top of the interior of the sign. An LED exit sign can cost between \$30 and \$250 in comparison to \$20 and \$100 for an incandescent and \$125 and \$200 for a fluorescent sign. Retrofit kits can be purchased to convert any exiting incandescent or fluorescent sign to an LED sign. The retrofit kit can cost \$40, which includes all the necessary hardware for the conversion.





**Figure 33. Interior view of an LED exit sign.**

### **3.7 Vehicle Exhaust Emissions**

Appendix B to this report details the characteristics of military vehicle exhausts, tails pipes and exhaust grilles. The following sections describe measures to reduce exhaust emissions.

#### **3.7.1 Reduce Vehicle Exhaust Emissions**

Some Army Depots and Tactical Equipment Maintenance facilities have poorly operating vehicle exhaust system. The flexible hoses used to connect to a vehicle's exhaust are quite stiff, are not designed to withstand high exhaust gas temperatures typical for heavy vehicles and tactical equipment and do not have connectors to fit different tail pipes of exhaust grills (Figures 34, 35, and 36).



**Figure 34. Example of vehicle exhausts at maintenance shop for A1M1 tanks.**



**Figure 35. New tactical equipment maintenance shop.**

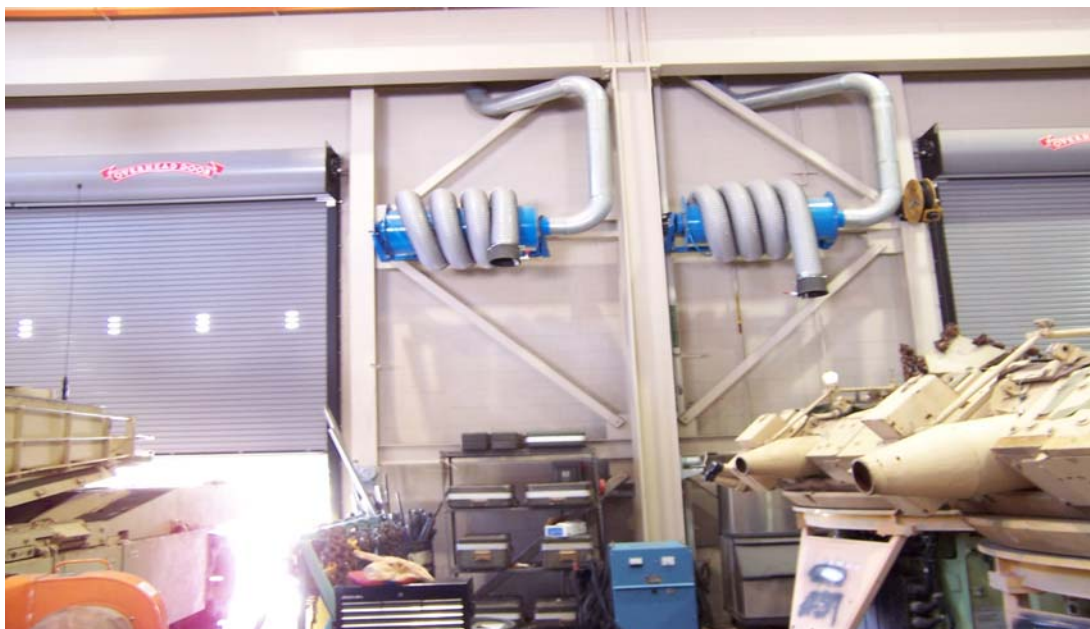


**Figure 36. Examples of tail pipes and exhaust grills of typically serviced military tactical equipment.**

The system runs most of the time and there are no dampers in the hose sections that could close if no vehicle is connected. Figure 37 shows a maintenance shop with a old central vehicle exhaust.



**Figure 37. Maintenance Shop with old central vehicle exhaust.**



**Figure 38. New individual vehicle exhaust with spring recoil hose reels.**

Figure 38 shows a maintenance ship with a newer central vehicle exhaust system.

It is recommended that spring recoil hose reels replace the hoses currently in place. Each would include tailpipe adapter, a damper and a fan motor starter to turn the fan on whenever the hose is pulled down for use.

A similar situation exists in the DPW Fleet Maintenance Shop at the same facility. Here a central system with flexible metal duct is used. The system works poorly and the hoses are too rigid to use. New exhaust system with a temperature resistant hose is recommended for this application.

The estimated cost for both spaces is \$68,000. Justification for the new systems is based on improved worker health and productivity.

### **3.8 Industrial Processes and Related Systems**

Industrial-related systems are energy users that are most often found in industrial plants. For the purposes of this report industrial-related systems include painting; ovens; metal finishing (plating); heat treat; metal casting; welding; and machining. Painting, ovens, metal finishing, welding and machining were common to all of the Arsenal and Depots. Heat treat and



metal casting were less common and specific to only one or two facilities in lesser or greater degree. Fort Stewart almost certainly had small painting and machining operations, however these were not part of the areas assessed at that facility.

### **3.8.1 Painting**

Painting is one of the most common operations at Army Arsenals, Depots and maintenance facilities. Among important factors affecting quality of the paint finish and a throughput of painting operations are ambient air temperature and relative humidity. Indoor air quality in the “breathing zone” (where people work in the paint area and adjacent spaces) depends on the type of paint used and its Volatile Organic Compound (VOC) content; the type of individual protection systems used by painters; the type of the process enclosure (open space; open, partially- enclosed, or totally- enclosed booth, etc.), process and building ventilation systems. These systems are significant energy users. This section discusses several measures allowing for increased productivity and energy conservation generally applicable to the Army painting processes. Appendix C presents some useful painting process-related information pertaining to efficiency improvement and energy use reduction in existing or new painting systems.

#### *3.8.1.1 Enclose Booth and Reduce Exhaust Air Flow*

At some facilities, painting is an operation that needs to be functioning all the time to meet scheduled shipping dates. As the result the ventilation systems for the paint booths and the ovens that support them are seldom turned off. The typical painting operation begins with preparing parts for painting (masking off areas not to be painted), painting the parts, and flashing and drying of the paint. Booth exhaust systems need to operate at full flow only during the painting and the flash-off phases. Some booths do not have doors or, if doors are present, the operators fail to close them. An open-type booth requires more exhaust air to properly control the paint fumes and solvents so they do not affect people working in adjacent spaces. Figure 39 shows an open booth at Rock Island Arsenal.



**Figure 39. Open paint spray booth having no doors or ceiling.**

The energy used by the booth's exhaust system can be reduced by mounting doors on the booths and installing variable speed drives on the exhaust fan motors. The improved booth enclosure will allow the total exhaust air flow to be reduced. The exhaust air can be further reduced when part painting and flash-off is completed. Reduction of exhaust air also allows a reduction of supply air required for the building make-up air. In the winter there is also a reduction in heating energy use due to the reduced quantities of outside air used.

The estimated cost to implement these changes is \$212,000, which will provide an annual energy savings of almost \$33,000 with a simple pay-back of 6 years. This project will save approximately 9 billion BTUs and 428 million watt hours (MWh) per year.

#### *3.8.1.2 Enlarge Oven for Complete Part Drying*

There is a paint booth followed by an oven that has a conveyor that transports the parts through the system. When using a urethane paint, which takes longer to dry, the parts must be cycled through the oven for a second time. No new parts can be painted when the second pass is occurring and the people doing the painting have nothing to do for this period of time. Figure 40 shows a small paint booth at Rock Island Arsenal.



**Figure 40. Paint booth with attached oven.**

If the oven was modified so that its area is doubled all parts that are painted could be dried in one pass. This would provide labor savings and also would reduce the time the paint/oven system would need to operate. The need to paint with a urethane coating occurs approximately 20 percent of the time. Another 30 percent of the time there is no painting due to a lack of parts or other reasons.

It is recommended that variable speed motors be installed on the booth and oven exhaust fans. This would allow a reduced exhaust and supply air flow to this equipment. The resulting energy savings approaches \$41,000. Adding this to the \$36,000 labor savings the total savings of the larger oven and variable speed drives is \$77,000. The purchase and installation costs of the larger oven will come to \$112,000, while installation of two drives is \$29,000. The annual energy savings amounts to 13.4 billion BTU and 180 MWh/yr, resulting in a simple payback of 2 years.

#### *3.8.1.3 Recirculate Air When Drying Painted Vehicles*

In a large drive-in booth, there is an exhaust system that operates whenever painting or drying is occurring inside the booth. The supply air system also must operate during these times. Energy can be saved by recirculating 70 percent of the exhaust air back into the booth/oven when the

paint coatings are drying. The drying operation occurs approximately 40 percent of the time. This recommendation would result in heat savings of almost 9.4 billion BTUs/yr. The installation of the duct changes would cost almost \$24,000. Figure 41 shows a large paint booth at one of the Depots; Figure 42 shows another smaller paint booth that discharges exhaust air outdoors.



**Figure 41. Large drive-in paint booth.**



**Figure 42. Booth exhaust fans that discharge outdoors.**



#### 3.8.1.4 *Modify Paint Booth Exhaust*

A good number of the paint booths at the Arsenals and Depots operate most or nearly all hours of the year. Approximately 30 percent of this time no painting is taking place in the booths, which would allow the air flow to be reduced. Using a reduction of 30 percent, the energy savings are over \$7,000/yr for one booth alone.

The cost to add dampers and ducts for air recirculation plus fan motor variable frequency drives (VFD) to this particular booth is almost \$50,000, providing a simple payback of nearly 7 years.

#### 3.8.1.5 *Add Vestibules to Paint Shop*

The paints that are used by the Army to coat their vehicles, equipment and components are best applied at room temperatures of 70 to 80 °F. After the paint has had a chance to flash-off, a slight amount of heat can be applied to aid the drying. After the item has dried to the touch, it will continue to cure at temperatures above 50 °F. At Sierra Army Depot there is a need to increase the painting capability. There is a project to add two new side draft booths in the building where two other booths are located. This building has space inside to park and place vehicles and equipment so they can warm up to a proper painting temperature in the winter. Building space is also needed to hold the painted items during their initial drying period if it is cold outside. The proposed location for the new booths is in the area used for drying, which means there would be little space to condition items to be painted in the new booths. Figure 43 shows the paint building at Sierra Army Depot.

A solution to this situation is to add vestibules to the paint building. Items stored outside could be placed in one vestibule to increase their temperature and to allow workers to perform other operations to get the items ready for painting. The other two vestibules would be used to park and place painted items so they can dry. The addition of these vestibules will allow a quicker flow of items through the paint shop. The space in the booth would be used for paint and flash-off only.



**Figure 43. Paint Building at Sierra Army Depot.**

The addition of these vestibules will improve worker productivity in the paint shop. Time spent inside the booths for part warm-up, preparation and drying will be avoided. Approximately 3,450 hrs/yr of painting time will be made available in the booths. When the booths are used for drying, etc. the painters are left with little to do. The labor cost of these lost hours equals \$165,000/yr. The cost to construct three vestibules having a total area of 1,350 sq ft is \$135,000. The use of these spaces will require an additional \$1,600 in annual energy costs. The resulting payback is less than 1 year.

#### 3.8.1.6 *Vary Exhaust from Paint Booths*

At Tobyhanna Army Depot there are eight medium-sized paint booths in one of their buildings. Each booth has a supply air system that provides air to the booth. There is also an exhaust system that removes air from the booth. Both fans of these systems are fixed drive and thus the air flow can vary due to changes in system static pressure. As filters become loaded with dirt and other particulates the static pressure increases. This causes a drop in air flow that affects the air balance between the supply and exhaust in each booth. Several booths were observed to have fumes present outside their doors. These fumes were caused by more supply air being sent to the booth than is removed or exhausted. The result is the excess air seeps out of the booth through opening around the booths doors. Figure 44 shows the paint booths at Sierra Army Depot.



**Figure 44. Row of eight paint booths at Sierra Army Depot.**

It is recommended that variable speed motors be installed on the supply and exhaust systems of the booths. One booth already has an installation of this type and performs well. These fans should be controlled in such a way that there is always more exhaust than supply air. Also, the total air flow can be reduced to 80 ft/minute (FPM) through the exhaust air openings without affecting the quantity of overspray. When paint spraying is being conducted the painter is wearing an air supplied protective face mask. This person will not be exposed to any fumes arising from the painting operation as a result of these changes.

With this reduction in air flow there is an electrical fan motor horsepower savings of \$13,000/yr. The reduction of supply air also reduces the amount of heat required (which amounts to \$14,000/yr). The cost of adding variable speed drives to the seven booths is \$140,000, resulting in a simple payback of 5 years.

#### *3.8.1.7 Use Roll Filter for Paint Particulates*

In some paint booths the exhaust air is pulled from the booth through a panel of cartridge or bag filters. A roll filter could be used to replace these filters to reduce the cost of filter changes. A roll filter has 2-in. media that is 65 ft long. One paint booth has a filter bank that is ten filters wide by seven filters high. Since the filters are 20 in. high by 20 in. wide, calcula-

tions reveal that the paint booth is approximately 12 ft high. The rolled ends of the filter will occupy a space 1½ ft high at the top and bottom of the filter area. Unless the top of the booth is modified to place the top roll out of the air stream the available filter area is reduced by 3 ft in height or 75 percent of the original height. If the top roll is out of the air stream, then 10½ ft is available for the filter media.

It is estimated the bag filters cost \$20 each, so the cost of replacing the 70 filters is then \$1,600. This includes 4 hours of labor at \$50/hr. With these filters being replaced every week the annual cost is \$80,000 for a 50 week year.

The roll filter does not have the same efficiency as the bag filters and thus will need to be cycled more to remove the paint particles. A 65 ft long roll will provide five cycles of clean media 12 ft in height. It is estimated the roll filters would need to be changed every 2 weeks at a cost of \$500 for the material and \$400 for 8 hours of labor. The annual cost to change the roll filters is \$22,500. Thus there is a \$57,000 savings per year in filter maintenance costs. The estimated cost for the roll filter system is then \$120,000 for a simple payback of 2 years.

#### 3.8.1.8 *Reduce Relative Humidity*

At Corpus Christi Army Depot, the outdoor humidity is often quite high due to its location on the Gulf of Mexico. Here most of the painting is a one shift operation. Painted parts are allowed to dry during the second and third shift periods. A primer (normally Mil Spec 22750) is first applied followed by an aliphatic polyurethane top coat (Mil Spec 46168D or 81352B). The control of humidity is very important for a proper paint finish. If the relative humidity (RH) is above 80 percent, the paint will not dry properly. Because of these conditions, all but one painting operation has air conditioning systems to lower the relative humidity. One painting area in the plating shop is not air conditioned and parts are heated before painting on humid days in an attempt to avoid this problem. Figure 45 shows one of the paint areas at Corpus Christi Army Depot.



**Figure 45. Open paint booth in non conditioned space.**

It is recommended that a 32-ton air conditioning unit be installed to provide cool air for the plating shop painting room at a cost of \$32,000. This will provide proper conditions for painting flash-off, drying and curing. This will also avoid having to heat parts in an oven to overcome the high humidity. It is estimated this is a problem approximately 5 percent of the time throughout the year. The estimated annual cost savings is \$7,300, which includes time to fix poorly painted parts and wasted paint. The resulting simple payback is 4 years.

### **3.8.2 Metal Finishing**

Heating tanks can account for more than 40 percent of energy costs in metal finishing. Efforts to reduce evaporation will also pay off, since more than 70 percent of heat loss from tanks occurs due to evaporation. Significant savings can be realized by covering tanks when not in use. Strategies to reduce evaporation will provide savings in both electricity and water consumption. Covering tanks when not in use may also improve quality by minimizing contamination.

#### **3.8.2.1      *Insulate High Temperature Plating Tanks***

Exposed surfaces on plating tanks often lead to energy losses that are not apparent. Minimizing heat loss from tanks with insulation can greatly reduce energy consumption. Figure 46 illustrates this point. At this plating shop (not one of the Arsenal or Depot shops), parts are being coated in the tank in the foreground. Note the cloud of mist containing both moisture and chemicals above the tank.



**Figure 46. Plating Shop heat and moisture loss.**

The majority of energy loss in plating tanks is caused by the transfer of heat from the tanks due to poor and/or no insulation. Installing at least 1 inch of insulation and performing regular inspections on the insulation will greatly reduce heat loss. Any metal processing facility that uses plating tanks should insulate the high temperature tanks to minimize heat loss. Insulating the surfaces of plating tanks can reduce the amount of heat given off by the tanks to atmosphere by up to 70 percent. The average cost for insulating a plating tank is \$40/sq ft. Depending on energy costs and the plating shop's operating hours, paybacks can range from 5 to 10 years.

Plating tank insulation will be most effective in regions with the greatest difference between ambient air temperature and the temperature of the tanks. Plating tank operations in the southern portion of the United States, which during the summer use outside air to condition the space, will experience lesser savings than the same shop in Maine.

#### **3.8.2.2**      *Install Covers on Chromium Plating Tanks*

During the chromium plating process, byproducts are created and emitted in the form of a chromic acid mist. Installing encapsulating tank covers on chromium plating tanks (Figures 48 and 47), would reduce and/or eliminate hexavalent chromium emissions, and would provide an added energy savings benefit as the tank cover acts as an insulating barrier.





**Figure 47. Chromium plating tanks.**



**Figure 48. Cover installed over a chromium plating tank.**

Tank covers contain fumes and mist within the tank such that water vapor that forms during the process condenses on the inside of the walls and the top of the enclosure. The condensate then returns to the tank, which results in a self-cleaning action. The tank cover contains the chromium mist because of the elimination of air movement inside of the tank. The heaviest byproduct rises to a limited height and then returns to the plating solution. The hydrogen and oxygen that are formed from the process escape through a membrane system.

Covers should be installed on chromium plating tanks. These covers will enclose the chromium tanks while the process is operating using a specialized sealing method. The membranes that are used in the sealing process

allow for the free passage of gasses, while blocking the escape of water vapor and chemical mists. This technology can be used at any facility that uses plating tanks. By installing covers on chromium tanks, energy and water use can be reduced by 60 to 70 percent. Installation costs are currently approximately \$50,000 or more per tank.

#### 3.8.2.3 *Use Plating Fixtures Allowing for Reduction of Plating Time and Labor for Parts Masking*

The process of masking can add significant costs to any operation; the more intricate a component, the longer it takes to apply and remove traditional masks. Custom plating fixtures can reduce the masking time. Figure 49 shows a plating fixture with parts over a plating tank at a non-DOD facility.

As part of the plating process, some parts need to be have portions of their structure masked so that only a certain area is plated while the remaining area is not exposed to the metal finishing chemicals. Figure 50 shows an example of masking, with the same part masked and then unmasked after the plating process.



**Figure 49. Plating fixture with parts.**





**Figure 50. Part masking (before and after plating).**

This technology results in a reduction in plating time and labor costs. Custom masking offers a number of advantages, including:

- eliminating the need to mask parts
- conforming anodes, which allows for maximum plating rates, reduced cycle times, and uniform deposits
- rapid and easy set-up, which reduces labor costs and operator training requirements
- exact centering, which allows for close anode to cathode spacing and results in faster plating rates and more uniform coatings
- multiple surfaces plating, which allows for simultaneous plating of eight or more different surfaces on landing gear or similar part
- high electrical connectivity/conductance that provides for a highly conductive copper connection below the solution level, without the possibility of bath contamination
- anode encasement, which allows for the protection of anode from bending/breakage, reducing worker exposure to lead-chromate film
- reduced air exhaust obstructions, with a streamlined design that avoids above solution obstructions.

Savings come from reduced plating time and labor costs, and reduced turnaround time, and depend a great deal on part configuration and alloys to be deposited, but reduction of up to 60 percent in plating time and a 50 percent reduction in turnaround time can be achieved. There would also be associated energy savings, as a reduction in plating time would reduce use, but such savings are highly dependent on the plating operation.

### 3.8.3 Heat Treat

Heat treatment operations are required to give steel parts the proper hardness and other qualities needed for the functions they will perform. These parts are heated in a furnace at specific temperatures and then cooled at scheduled rates. The environment in such a space is hot and often smoky. The warm temperatures are the result the heating operations. Smoke is present due to oil on the parts burning off when heated and the oil quenches used to cool parts. Figures 51 and 52 show a heat treat shop and its ventilation system.

Good ventilation of the heat treat area is often difficult. Normally a crane operates overhead requiring exhaust ducts from processes and those for ventilation to fit in the space between the crane rails or the crane rail and the building wall. The heat in the space rises quickly creating a thermal lift that causes outside air to infiltrate into the building, especially at lower elevations. This outdoor air flow causes cold drafts in the winter.

At one heat treating operation the ventilation of the space is provided by a 32,500 CFM AHU located high up in the building. Air is discharged from this unit at 130 °F through diffusers approximately 30 ft above the floor. None of this heated air is reaching the worker occupied level. The AHU was also handling 10 percent outside air, which is not enough to dilute the heat and smoke generated below. A more effective ventilation system is clearly needed.



**Figure 51. View of heat treat shop with AHU and ventilation air outlets above.**



**Figure 52. Hoods over entrance of heat furnaces.**

#### 3.8.3.1 *Upgrade Heat Treat Ventilation System*

This AHU should have its duct distribution system modified to deliver the supply air at the worker level. Ducts that run down the walls behind the crane rails will accomplish this. A supplemental gas fired make-up air unit will be placed outside and adjacent to the heat treat operations. This unit can be used for additional ventilation air when space conditions become smoky and/or too warm. A new control for starting the local exhaust fans in the area is also required.

Also recommended is the installation of exhaust hoods to capture heat and smoke off the worst of the heat treat operations. The estimated cost to make these modifications approach \$180,000. The justification of the project is improved conditions in the heat treat working area. Figure 53 shows a front-loading heat treat furnace and Figure 54 shows a vertical heat treat furnace.

The discharge temperature from the existing AHU can be reduced, saving \$1,600/yr. The warm air in the upper part of the building can be mixed with the outside air with this AHU and then delivered down to where the people are. The project has a long payback, but should be implemented to provide good environmental conditions.



**Figure 53. Typical heat treat furnace with door open.**



**Figure 54. Typical vertical heat treat furnace.**

### 3.8.3.2 *Metal Casting*

Rock Island Arsenal is the Army's sole remaining foundry. The Army, and DOD, has need for small lot repair parts and rapid manufacturing capability that is fulfilled by the RIA foundry, which is often the critical first element in the parts supply chain.

A casting is a metal part formed by pouring molten iron, steel, aluminum, zinc, titanium, magnesium, copper, brass, bronze or cobalt, in nearly all cases from recycled materials, into a mold or dies. Virtually any metal that can be melted can and is cast. Sometimes these castings are used as produced, but more often they are machined or heat-treated and used as components of assembled products.

### 3.8.3.3 *Install Static Frequency Converters on Induction Furnaces*

Static frequency converters (current or voltage) supply a variable frequency to the furnace induction coil, which varies to match the type of material being melted and the amount of material in the furnace. Static power converters are used in induction melting systems to convert standard frequency (50 or 60 Hz) and constant voltage electric power into variable medium frequency (200-1000 Hz) and voltage (on the order of 3,000V) to be applied to an induction furnace. In recent years, the foundry and steel-making industries began to acquire induction melting systems with solid state power converters operating at a power level of about 10,000 kW in a single installation. Static frequency converters require low maintenance and have high efficiencies, resulting in low life-cycle costs.

A static frequency converter can reduce electricity consumption by a furnace anywhere from 10 to 15 percent, depending on the size of the unit and the operating hours. The cost of static frequency converters ranges from a low of \$6,000 for a smaller unit to as high as several tens of thousands of dollars for larger units.

### 3.8.3.4 *Adopt Molten Metal Blanketing*

Molten metal blanketing (MMB) uses significantly less gas than similar technologies while preventing oxidation and gas pickup into molten metals by displacing the atmospheric oxygen and water vapor with a dry and inert



atmosphere composed of argon or nitrogen. Figure 55 shows a uniform amount of inert, liquefied gas being sprayed into an induction furnace. This results in a two-phase gas blanket over the entire bath surface.

Molten metal blanketing uses the expansion characteristics of nitrogen or argon to keep the atmospheric air away from the molten metal surface, and to provide a uniform, inert gas atmosphere on the metal surface. There are two types of molten metal blanketing. Liquid spray type uses a swirl-spraying device to produce a layer of liquefied inert gas over the metal surface. The sprayer delivers an even amount of fine, liquid droplets across the furnace. This results in a uniform two-phase gas blanket over the entire bath surface and eliminates excessive liquid phase accumulation on the molten metal.

This method has been proven safe and is efficient from a gas consumption standpoint. Gas blanketing type sends inert gas through a ceramic swirl cone at a predetermined flow rate, causing the gas to expand and swirl just above the bath surface. Gas blanketing enables the furnace to remain open at all times, allowing unobstructed access to the molten metal.



**Figure 55. Gas blanketing of molten metal.**

Molten metal blanketing can be used to prevent the formation of oxides in both ferrous and nonferrous metals being melted in induction furnaces. Due to reduced consumption of argon or nitrogen, molten metal blanketing technologies provide a 40 to 60 percent cost savings, compared with other blanketing techniques. The loss of high-priced alloys is also minimized, while slag or dross rates are cut in half to help decrease disposal costs.

### **3.8.4 Welding Operations**

Welding is a major operation in the rebuilding of Army vehicles and other equipment. There are a number of welder work stations at facilities having a rebuilding and repair mission. Welding generates metallic fumes that must be exhausted. Large exhaust systems with hood in every welding booth are normally found in these facilities. These systems operate all day removing significant amounts of air from the building. Heating energy is required to temper the replacement supply air and electrical power is used by the supply and exhaust fan motors.

There are welding exhaust systems available that exhaust air from a welding booth only when there is welding being done. This system also has specially designed hoods that can be placed very close to where the welding is taking place thus lowering the exhaust air flow for good capture. The use of this system results in a lower replacement air flow and the reduced fan motor horsepower use.

#### **3.8.4.1**      *Use New Demand Based Welding Exhaust System*

At one Army Arsenal, 33 welding booths are served by three welding exhaust systems operating at a full capacity throughout the day. These systems have exhaust extraction arms that should provide close capture of the welding fumes, but the arms are old and it is difficult to position them close the welding zone. Thick layer of welding fume particles accumulated on the internal surfaces of extraction arms is blocking the air passage and thus reducing the amount of exhaust air to about a third of the design rate. As the result, working conditions in the welding area are smoky with the odor of welding fumes. To keep the welding area clear of these contaminants, the building's general exhaust system operates most of the time. This system was installed for occasional use, but since local exhaust systems are not functioning correctly, the general exhaust fans always remain



on. As the result, approximately 150,000 CFM is removed from the building and an equal amount must be heated in the winter by the supply air system.

The local welding system needs to have new exhaust arms installed that the operators can easily move them close to their welding locations. This will allow the capture of the welding fumes and gases. New demand controlled ventilation system will exhaust contaminated air from each welding stations only during the welding process. Demand based control of the local exhaust system will be initiated by a light sensor or a current (inductive) sensor attached to the welding machine. Each of these sensors will initiate the activation of an air flow from a specific hood during actual weld time. The system fan ramps to accommodate the number of hoods activated without affecting airflows through other hoods.

A demand based system (Figure 56) allows for reduction of exhaust duct, fan and a filter size and its operating airflow rate. It also reduces the size and operating airflow of the make-up air system. The exhaust airflow rate is controlled using a VFD and a pressure sensor installed in the main duct. Typically a demand controlled local exhaust system is sized for not more than 50 percent of the total airflow rate exhausted through all hoods (maximum capacity of the standard constant volume system). Installation of the demand based local exhaust system is economical when the system has at least three extraction hoods and applies to welding processes with duty cycles under 70 percent.



**Figure 56. Schematic of a welding shop demand based local exhaust system.**

The proposed exhaust rate through each hood will be approximately 700 CFM of air compared to an average of below 300 CFM with the current system.

Since the old exhaust system had high pressure drops in the system, the new system will provide electrical energy savings. Lighter use of the general ventilation system will also yield electrical savings. A total of \$20,000/yr will result from the reduced electrical use. Heating of the outside air will also be reduced by a cost of \$16,000, for a total cost savings of \$36,000/yr.

The installation of new arms and booms is estimated to cost \$115,000, which includes individual work station dampers and sensors and VFDs with a pressure sensors for the three exhaust fan motors. The simple pay-back of this project is 4 years.

#### 3.8.4.2 *Install New Welding Boom Arms*

The main welding shop at Sierra Army Depot is building space approximately 300 ft long by 60 ft wide. There are nine welding stations in the building, four are along the east wall in the north of the building and the rest are along the west wall on the south end. The Welding Smoke Removal system used in this building is comprised of two separate systems, each using four or five pivoting boom arms connected to a fan. All of the welding fume extraction devices incorporate a 10-ft long pivoting boom and a 10-ft long extraction arm attached to the end.

It is proposed to replace the boom arms with new pivoting boom arms that will be able to reach all necessary locations. Electric actuated dampers will be added to each extraction arm location with either a sensor or manual switch to open the damper when welding is occurring. A frequency inverter and pressure transmitter will be added to the existing fans. This control system will conserve electrical energy since the fan will only operate at a level equal to the need. It will also save heating energy as the exhaust system will only exhaust air is needed to do the level of exhaust required. The estimated energy savings of the modified system is almost \$1,000/yr.

The welding system modification will cost approximately \$46,000. The total annual savings is \$58,000, providing a simple payback of less than 1 year. Many of the arms are in poor condition and nearly unusable by the welders. A major complaint from the welders is that the arms are either too long or too short for their needs (depending on where they are working or the size of the equipment they are working on). The booms are very difficult to pivot and the extraction arms have limited vertical movement. It is estimated that the welders use an extra 30 minutes a day positioning these welding hoods into place. Since there are 10 welders normally working, this extra time has an annual value of \$57,000. Figures 57 and 58 show two of the existing types of welding extraction arms. Figure 59 shows the proposed flexible extraction arms, which are easier to operate and position close to the welding zone.



**Figure 57. Current weld booms with extraction arms.**



**Figure 58. Welding boom extraction arm.**



**Figure 59. Welding boom with flexible extraction arms.**

#### 3.8.4.3 *Upgrade Welding Exhaust Equipment*

Tobyhanna Army Depot has two welding centers in the manufacturing complex. The first has 16 welding booths, with each pair of units served by a smoke eater welding fume collector. The system is often not used due to the difficulty of positioning the welding arms in the proper location and the unpleasant noise the units make. The other welding location had several welding booths that were exhausted using a central system. Currently only three of the booths are in use. The exhaust system is seldom used due to the noise it makes. Figures 60-62 shows the welding centers.

It is proposed that the old welding arms be replaced with new ones in the first welding area. Also the welding fume collectors should be relocated so their discharge is into the working area. A controller should be installed on each unit for turning the collector off when welding is not taking place. For the second welding area, three portable welder exhaust units are recommended. The estimated cost for these improvements is \$62,000. The installation of this equipment can be justified through improved worker health and productivity and better indoor air quality.

#### **3.8.5 Machining Operations**

Machining operations consist of numerous machines positioned to perform various metal cutting tasks required to finish a part. Electric motors power these machines. Temperature control is normally not a concern with these operations, while good lighting is important for accomplishing many of the tasks.

Machining of metal often requires a cutting fluid to cool the cutting tool, to remove chips, and to aid the cutting process. These cutting fluids are normally oil based and their use can create oil and smoke emissions into the air. To control this emission the machining operation is enclosed or hoods are provided. An exhaust fan and air cleaner is also needed to capture and remove the contaminants.





**Figure 60. Recirculating welding exhaust systems.**



**Figure 61. Current active welding stations.**



**Figure 62. Storage area served by welding exhaust system.**

#### *3.8.5.1 Provide Exhaust Systems*

Corpus Christi Army Depot is currently purchasing a number of new computerized numerical controlled (CNC) grinding and other metal cutting machines. These machines generally come with enclosures to minimize noise and to contain the oil mist generated as the machines operate. To be most effective these machines need to have their enclosures exhausted so contaminants created by the machining process are controlled. For those locations where a number of machines are close together a centralized mist collector should be used. This will have a lower installed cost than a number of individual units and maintenance on the central equipment will also be less. Figures 63 and 64 show two oil mist collection hoods.

For the enclosures in use, the exhaust air flow rate will be approximately 500 CFM each. Rather than installing individual exhaust filter units, use a centralized system to reduce the installation and maintenance costs. Once the location of these machines is known, those machines adjacent to them can be served by a central air cleaner and a fan unit.





**Figure 63. Oil mist collection hoods in machining shop.**



**Figure 64. Oil mist collector with a hood.**

Maintenance costs of a central system will run approximately \$1,000/yr since fewer machines require attention as compared to individual units. The system will incur additional electrical energy use of approximately 2,000 kWh/yr since individual exhaust filters can be shut down when their respective machines are not operating. The central exhaust filter systems have to run even when only one of the machines it serves is on. This additional electrical energy has a value of \$110/yr.

Total system savings is approximately \$900/yr. Installation of these exhaust filters will increase the amount of clean air in the workspace, reducing occurrences of employee illness and decreasing housekeeping costs.

The approximate cost of a single filtered exhaust unit is \$6,000 for a 500 CFM unit. Assuming 17 of these units are needed, the total cost would be \$102,000. If four central filter stations are used, the cost for the installation would be approximately \$60,000, resulting in annual savings of \$42,000. This project would have an immediate payback since the installed cost of the central systems is lower than the individual units.

## **4 Benchmarking**

### **4.1 Methodology**

Energy benchmarking conducted by the Energy Resource Center (ERC) and CERL included the development of quantitative and qualitative indicators by collecting and analyzing energy-related data and energy management practices at Army Arsenals, Depots, and one Naval Aviation Depot, and comparing these indicators among each other and against private industry. These benchmarks will allow the Arsenals and Depots to compare their energy use and practices with similar operations elsewhere. These indicators can help guide Arsenals and Depots toward achieving greater energy efficiency by identifying energy cost-saving opportunities for each energy consuming system.

#### **4.1.1 Identification of Processes**

Drawing on the energy and process optimization assessment experiences at Army industrial bases and prior energy audits at other DoD facilities, CERL identified four processes suitable for benchmarking that are present at one or more Arsenals and/or Depots:

- metal casting (installation at Rock Island Arsenal)
- metal finishing (installations at Rock Island Arsenal, Tobyhanna Army Depot and Corpus Christi Army Depot)
- painting (installations at all facilities)
- heat treat (installations at Rock Island Arsenal and Corpus Christi Army Depot).

These processes were chosen because they are all major consumers of energy and because they are located at many DoD facilities in general and Army Arsenals and Depots in particular. Additionally, since these processes are also found in private industry, it makes it possible to compare Army practices with counterpart activities in the general manufacturing sector. In one case (metal finishing), the U.S. Navy facility at Naval Aviation Depot (NADEP) San Diego was also surveyed and the information gained incorporated into this report.

#### **4.1.2 Identification of Systems Supporting the Processes**

To accurately benchmark these systems, measurements and information for both the primary and supporting systems were used. For example, metal casting involves a direct measurement of the kilowatt-hour used by the furnace, a primary system, during a melt. A supporting system for the metal casting operation would be the HVAC system that cleans the air of heat and fumes. Measurement of the energy used by the HVAC system would be included in the benchmark.

Additionally, measurements and information for both local and satellite operations were used. In the painting process, motors that work to exhaust harmful volatile organic compounds (VOC) are located immediately adjacent to the paint booths. These motors are considered to be local systems and were taken into account when measuring energy use by the paint booths. The paint booths also used compressed air to atomize the paint, although the air compressors are (for the most part) located some distance away from the painting operation. In this case, the air compressors are considered to be satellite operations that must be taken into account when determining the energy consumption of the painting operation.

#### **4.1.3 Measurement of Systems**

A number of different methods were used to determine the energy use of the various systems. Because of the sporadic nature of the work at the Arsenals and Depots, combinations of methods and information were used to determine the most accurate possible use profiles of the energy using systems.

Nameplate data were gathered from most of the energy-using systems. Much of the information necessary to determine energy consumption can be generally obtained from the nameplate of the piece of equipment being studied. Oftentimes the nameplates were accessible, but in some cases the nameplates were difficult to read, illegible, or missing. In these cases, information was sought out from drawings and materials held by the Arsenals and Depots in their technical libraries, individual shops or maintenance areas. Interviews with Arsenal and Depot personnel, specifically shop workers, supervisors, maintenance staff, and Department of Public Works (DPW) workers were conducted to determine how the various systems were used in terms of operation patterns, operating time, partial and

full loading and other service patterns. Any information or past studies regarding each of the systems was sought, including proposals by various vendors, replacement options the shop had been considering, and metering and submetering logs. In some cases, direct measurement of voltages and amperages was considered and discarded due to the high voltages present in the Arsenals and Depots and the associated time it would take to get an electrician on site to put on and take off measuring equipment.

#### **4.1.4 Quantification of Energy Use**

To quantify the energy use of the various systems, the information regarding power measurements and/or energy use was compared against operating patterns and equipment loads to determine a base number for how much energy was used. This number was then adjusted by various factors including usage time, system efficiency, and other factors that came to light during review of operating information and/or interviews with plant personnel. Taking all of these factors into account, a number was generated for the total energy use of the particular piece of equipment that reflected all of the information and assumptions known and made about the system.

#### **4.1.5 Determination of Product/Point of Comparison**

Energy benchmarking involves the development of quantitative and qualitative indicators through the collection and analysis of energy-related data and energy management practices. Energy performance benchmarking focuses on a comparative analysis of energy use per unit of physical production, otherwise known as energy intensity. Energy intensity is measured by the quantity of energy required per unit output or activity, so that using less energy to produce a product reduces the intensity. Energy efficiency, on the other hand, improves when a given level of service is provided with reduced amounts of energy inputs, or when services are enhanced for a given amount of energy input.

The distinction between energy intensity and energy efficiency is important because improvements in processes and equipment and other explanatory factors can contribute to observed changes in energy intensity. In general, the unit of physical production chosen has to be directly related to the process, and the energy used to make that product must be measurable.

If these quantitative factors are not available, a qualitative comparison can still be made to identify those items that make one system or operation more efficient than another similar system or operation. Qualitative factors, while not as detailed as quantitative factors, are useful indicators that can allow strengths and weaknesses to be better identified.

## **4.2 Energy Density Comparison**

### **4.2.1 Quantitative Comparisons**

Where feasible, quantitative comparisons were made between the process and similar processes conducted at private industrial plants that had assessments conducted as part of the Industrial Assessment Center (IAC) program. The IAC Program, overseen by the U.S. Department of Energy, provides eligible small- and medium-sized manufacturers with no-cost energy assessments. Teams composed mainly of engineering faculty and students from the centers, located at 26 universities around the country, conduct energy audits or industrial assessments and provide recommendations to manufacturers to help them identify opportunities to improve productivity, reduce waste, and save energy. To be eligible for an IAC assessment, a manufacturing plant must meet certain criteria. It must:

- fall within Standard Industrial Classification (SIC) 20-39
- be located within 200 miles of a host campus
- have gross annual sales below \$100 million
- employ fewer than 500 employees at the plant site
- have annual energy bills more than \$100,000 and less than \$2.5 million
- employ no professional in-house staff to perform the assessment.

In conjunction with its industrial assessment work, the IAC Program maintains a database of plant and related assessment information (individual plants are not identified in keeping with Program policies) recording the actual results of approximately 13,000 assessments conducted by the Program since 1980.

The IAC Database currently contains detailed data, available by Standard Industrial Classification (SIC), fuel type, base plant energy consumption, and recommended energy-efficiency improvements. Projected energy sav-

ings, cost savings, implementation cost, and simple payback are provided for each recommended measure. These data allow plants to make comparisons against similar facilities and know what types of efficiency, waste reduction and productivity improvements were most frequently recommended. It also helps facilities identify the measures most likely to be of interest, and provides actual implementation costs and paybacks on the selected measures. Specific information available as part of the database used in the quantitative comparison includes annual energy use (electricity and/or natural gas); annual production (units, pounds, pieces, etc.); and plant parameters (size, operating hours).

Despite the large number of assessments and the information available for each plant, the IAC database does have its limitations. It is not entirely comprehensive in that all of the information detailed in each assessment report is not incorporated into the database. This becomes problematic in that key information necessary to conduct benchmarking is not available. For example, each assessment report details the equipment found at the plant, including energy ratings. This information would be useful in conducting the metal casting benchmark analysis as it would allow the energy use of the furnaces to be isolated from that of the total energy use of the plant. Unfortunately, this information is not incorporated into the database. Inquiries made to the Center for Advanced Energy Systems (CAES), the Program Manager for the IAC Program, revealed that the assessment reports could not be made available as release of the more detailed information may violate nondisclosure agreements made between the individual IACs and the plants, and possibly be a violation of the contract between CAES and the Department of Energy.

Another limitation is that the assessment locations are unknown, which may dramatically affect how the values in the database should be interpreted. For example, two metal-finishing plants with similar equipment, products and output will have dramatically different energy use figures depending on their particular location. A plant located in a portion of the United States with a long heating season will use more energy for space conditioning than a plant located in a region of the United States with a much shorter heating season. Finally, these two same plants might have their production units reported entirely differently. One plant might report the number of pieces produced, while a second plant might report the total weight of their annual production. All of these limitations limit the effec-

tiveness of IAC Database when conducting benchmarking comparisons. No other information source offers the breadth and depth of the figures contained in the IAC Database, so despite its limitations it remains the preeminent source of industrial data for quantitative comparisons.

#### **4.2.2 Qualitative Comparison**

When quantitative comparisons could not be made between Army processes and similar processes conducted at private industrial plants that had assessments conducted as part of the Industrial Assessment Center (IAC) program, a qualitative comparison was made. This qualitative comparison examined the practices at the painting and metal finishing operations at the respective Arsenals and Depots and focused on what they were doing well versus what activities and actions could be improved.

### **4.3 Arsenals and Depots**

Metal casting is found only at Rock Island Arsenal (RIA), while metal finishing is found at RIA, Corpus Christi Army Depot (CCAD) and Tobyhanna Army Depot (TYAD), and the Naval Aviation Depot (NADEP) at San Diego. Heat treat is found at RIA and CCAD, while painting is found at all four facilities (RIA, CCAD, TYAD and SIAD). Below is a short description of each of the facilities assessed.

#### **4.3.1 Rock Island Arsenal**

The Rock Island Arsenal is an active Army installation located on an island in the Mississippi River between Rock Island, IL, and Davenport, IA. The island is 3 miles long and ½ mile wide. The island hosts three major and several minor activities. The major activities include the Rock Island Arsenal, the U.S. Army Corps of Engineers – Rock Island District, and the National Cemetery. As the largest government-owned government-operated weapons manufacturing arsenal in United States, the Rock Island Arsenal provides manufacturing, logistics, and base support services for the Armed Forces. The Arsenal is an active U.S. Army factory that manufactures ordnance and equipment for the Armed Forces. Some of the Arsenal's most successful manufactured products include the M198 and M119 Towed Howitzers and the M1A1 Gun Mount.



Noted for its expertise in the manufacture of weapons and weapon components, every phase of development and production is available from prototype to full-scale production of major items, spare parts, and repair items. Product items range from artillery gun mounts and recoil mechanisms to aircraft weapons subsystems. Items manufactured at RIA include artillery, gun mounts, recoil mechanisms, small arms, aircraft weapons sub-system, grenade launchers, weapons simulators, and a host of associated components. This manufacturing mission has been called on to support short-notice, critical items for soldiers in the field, including armored door kits for Humvees (HMMVVs), weapons pedestals and electronic night sights for troops in Iraq and Afghanistan.

#### **4.3.2 Corpus Christi Army Depot**

Corpus Christi Army Depot (CCAD) is located on Naval Aviation Station (NAS) Corpus Christi. NAS Corpus Christi is located 10 miles southeast of the city of Corpus Christi, TX on Corpus Christi Bay.

The mission of CCAD is to perform depot maintenance on Army aircraft and aeronautical equipment, to training military personnel in aeronautical depot maintenance for assignment worldwide and to prepare aircraft for overseas shipment. The Depot also is responsible for distribution of overhauled items and for maintaining a mobilization base capable of rapid expansion in the event of a national emergency.

Corpus Christi Army Depot is the Army's only organic facility for the repair and overhaul of rotary wing aircraft. The Depot is a major contributor of the Army, Navy, Marine Corps, and Air Force readiness through repair, overhaul, and maintenance of a wide variety of helicopters and related engines and components.

Corpus Christi Army Depot possesses extensive manufacturing capabilities that use conventional and advanced technology processes. This provides rapid, economical machining of a wide variety of ferrous and nonferrous materials. The Depot fabricates aircraft parts that are not currently available from standard sources, enabling the Depot to provide timely aviation maintenance service to customers. Today, CCAD provides helicopter repair and overhaul capability to all the U.S. military services, and to many foreign military organizations. Thirty percent of the Depot's workload is

obtained from other services and includes the SH-60 Seahawk, AH-1W Super Cobra Attack Helicopter, MH-60 Pavehawk, and UH-1N Huey Helicopter.

#### **4.3.3 Sierra Army Depot**

Sierra Army Depot (SIAD) is a government-owned, government-operated installation. SIAD is located in Herlong, CA, east of the Sierra Nevada Mountains. Sierra Army Depot is a munitions disposal site for the U.S. Army. It is licensed in California and operated by a civilian contractor working for the U.S. Army. The depot's main mission is the disassembly and destruction of conventional ammunition. Its secondary missions include industrial repairs and support of warfighter requirements, storage of equipment, and the static storage of ores.

SIAD receives, issues, stores, renovates, and demilitarizes (destroys) ammunition. Three facilities are identified specifically for demilitarization of ammunition at SIAD. The deactivation furnace is an incinerator that can demilitarize small arms ammunition, primers, fuses, and boosters. The Depot has approval from the state of California to demilitarize up to 0.50 caliber rounds in the deactivation furnace. For larger stocks, two general purpose buildings are used to download and pull apart ammunition for demilitarization. They are equipped with intrusion detection systems and rapid response deluge systems for safety.

SIAD is licensed by the Nuclear Regulatory Commission to receive, store, issue, renovate, and demilitarize (disassemble) depleted uranium rounds. SIAD has the largest open burn/open detonation capacity in the United States. Fourteen pits, permitted by the State of California, can detonate up to 10,000 lbs net explosive weight per pit. The Depot is also able to burn materials up to 100,000 lbs in net explosive weight. The open detonation pits are also used to dispose of large rocket motors.

#### **4.3.4 Tobyhanna Army Depot**

Tobyhanna Army Depot (TYAD) is located in the Pocono mountains of northeastern Pennsylvania, 20 miles southeast of Scranton. The Depot performs worldwide depot level maintenance repair, overhaul, and fabrication support for ground, airborne, navigational, and satellite communications-electronics equipment and missile systems.

Tobyhanna Army Depot is the Department of Defense's primary facility for repair, overhaul, maintenance, integration, fabrication, upgrade, and total life-cycle support of communications-electronics equipment and systems. TYAD is the largest, full-service communications and electronics maintenance facility in the Department of Defense. In late 2003, TYAD finished construction of its new Industrial Operations Facility (IOF). The IOF is a 91,000 sq ft facility designed to refinish the multitude of component parts used in the various communications-electronics systems repaired or overhauled at TYAD. The IOF was designed for optimum utilization of personnel, equipment, processing, and material. It consolidates painting, metal finishing, sandblast, ultrasonic and steam cleaning operations, and the chemistry laboratory into an integrated ISO 9001-certified facility.

#### **4.3.5 Naval Aviation Depot, San Diego**

Naval Aviation Depot (NADEP) is a manufacturing, maintenance and repair facility for aircraft and ship components. The NADEP mission includes a complete range of depot level rework operations on designated weapons systems, accessories and equipment, manufacturing parts and assemblies, providing engineering services, and assisting in resolving aircraft maintenance and logistics problems. The facility is located in the City of Coronado. It is bordered on the north and west by San Diego Bay, on the east by residential neighborhoods of the City of Coronado, and on the south by the Pacific Ocean.

The NADEP operates in one of the more stringently regulated areas of the United States. This is of special note as NADEP is the largest industrial facility and the largest metal plating facility in San Diego. Because of the amount and variety of industrial activities being performed at NADEP with the multitude of environmental regulatory drivers, and because the "low hanging fruit" pollution prevention projects have been implemented for some time, NADEP has implemented several innovative pollution prevention projects in the plating shop with energy efficiency applications.

### **4.4 Rutgers Database Information**

#### **4.4.1 Metal Casting**

The Industrial Assessment Center (IAC) database held by the Center for Advanced Energy Studies (CAES) at Rutgers University contains summa-

rizes over 11,000 IAC reports. Of these, there are over 2,000 reports detailing plants that have a primary Standard Industrial Classification (SIC) code of 33XX, which covers plants that are engaged in smelting and refining ferrous and nonferrous metals from ore, pig, or scrap; in rolling, drawing, and alloying metals; in manufacturing castings and other basic metal products; and in manufacturing nails, spikes, and insulated wire and cable. This major group includes the production of coke.

Information from a total of 70 plants with SIC code 33XX was retrieved from the IAC database. All of these plants were assessed over a 4 year period (2002, 2003, 2004, and 2005). Of these, a total of 58 plants were found to have enough relevant information to conduct a comparison. Further analysis reduced this number to 53 plants, which were then compared against the metal casting operation at RIA. The IAC database for the metal casters details their annual energy use in terms of both electricity and natural gas. Information from the database indicates that all these plants use electricity to melt metal. To ensure an accurate comparison, kilowatt-hours were chosen as a common unit for all of the plants and RIA.

The database does not allow isolation of any one particular energy-using system, which means that the energy use of the melting furnaces cannot be broken out from the energy use of the plant. For example, the energy used to compress air at the facility cannot be determined, only the energy use of the entire plant. This differs from the energy use as measured at RIA, which details only the energy use of the foundry area. As opposed to the metal finishers, a leveling factor is not used here to isolate the production energy use from that of the nonproduction areas, such as offices, storage, and maintenance. The assumption here is that the production areas of the plants in the IAC database account for the vast majority of the total plant energy use. This is because metal melting by the furnaces is much more energy intensive than any other operation in the plant and therefore accounts for more than 90 percent of the plant's total energy use.

Each of these plants also had a figure detailing the total amount of metal that particular facility melted over the year previous to the assessment, measured in tons. To ensure an accurate comparison, only iron and steel foundries, specifically steel investment foundries and other steel foundries not elsewhere classified (SIC codes 3324 and 3325), were drawn from the

IAC database. These are the two types of foundry that are most similar to melting operations conducted at RIA, which mostly melts steel.

The annual energy use in kilowatt hour for the plants ranges widely, from a little less than 500,000 kWh to over 60 million kWh/yr. Production also ranges widely, from a low of 220 tons/yr to nearly 34,000 tons/yr. As a result, the energy density of these plants, which compares the annual energy use in kWh against the annual production in tons, also ranges widely. The energy density of these plants ranges from less than 1,000 kWh to over 50,000 kWh/ton of metal melted. There appears to be little correlation between the annual operating hours, tons of production and electricity consumption (kWh/year) and the resulting energy densities of the various plants. There is a broad range of energy densities, and hence energy efficiencies, at these plants. Table 3 lists these energy densities, along with the supporting energy use and production values for all the plants.

#### **4.4.2 Metal Finishing**

The IAC database also contains over 4,300 reports detailing plants that have a primary Standard Industrial Classification (SIC) code of 34XX. This major group includes establishments engaged in fabricating ferrous and nonferrous metal products, such as metal cans, tin-ware, hand tools, cutlery, general hardware, nonelectric heating apparatus, fabricated structural metal products, metal forgings, metal stampings, ordnance (except vehicles and guided missiles), and a variety of metal and wire products, not elsewhere classified.

Plants specializing in electroplating (SIC 3471) were chosen from this group for benchmarking. Establishments under this SIC are primarily engaged in all types of electroplating, plating, anodizing, coloring, and finishing of metals and formed products for the trade. Also included in this industry are establishments that perform these types of activities, on their own account, on purchased metals or formed products. This classification best represents the activities of the metal finishing operations at RIA, CCAD, and TYAD.

**Table 3. Metal casting energy density.**

Rank	Plant	SIC	Production Hours (hrs/year)	Production Size (sq ft)	Tons of Production (tons/year)	Demand Consumption (kW/year)	Electricity Consumption (kWh/year)	Energy Density (kWh/ton)
1	58	3325	6,060	Unk	29,000	Unk	3,024,619	104
2	RIA	3325	NA	NA	916	NA	600,740	656
3	15	3325	6,576	168,000	12,000	19,654	8,139,600	678
4	21	3325	6,576	Unk	12,000	19,654	8,139,600	678
5	6	3324	5,434	Unk	4,000	Unk	3,114,596	779
6	37	3325	6,120	Unk	494	Unk	438,746	888
7	49	3325	8,760	Unk	33,911	130,395	35,057,445	1,034
8	43	3325	3,120	Unk	4,800	Unk	5,068,875	1,056
9	20	3325	2,277	Unk	3,000	24,257	3,335,580	1,112
10	46	3325	6,240	Unk	1,154	Unk	1,588,511	1,377
11	52	3325	2,880	Unk	2,400	Unk	3,446,366	1,436
12	23	3325	8,400	Unk	18,000	176,600	27,550,704	1,531
13	25	3325	3,120	Unk	1,000	Unk	1,661,196	1,661
14	42	3325	4,500	Unk	1,120	Unk	1,911,196	1,706
15	28	3325	3,960	Unk	13,000	Unk	23,043,670	1,773
16	48	3325	7,200	Unk	5,800	Unk	10,461,020	1,804
17	36	3325	2,340	Unk	6,000	Unk	10,852,872	1,809
18	38	3325	4,420	Unk	5,000	Unk	9,355,508	1,871
19	56	3325	6,600	Unk	2,250	10,434	4,327,081	1,923
20	41	3325	6,000	Unk	11,000	115,782	21,322,611	1,938
21	40	3325	5,880	Unk	2,700	19,936	5,450,469	2,019
22	13	3325	4,160	199,500	12,000	28,476	24,383,273	2,032
23	31	3325	4,160	Unk	12,000	28,476	24,383,273	2,032
24	19	3325	3,980	Unk	2,350	23,959	4,974,502	2,117
25	29	3325	6,760	Unk	6,000	61,812	12,726,260	2,121
26	51	3325	2,080	Unk	420	Unk	931,125	2,217
27	33	3325	4,000	Unk	6,200	Unk	13,985,053	2,256
28	54	3325	6,240	Unk	14,600	168,696	34,081,478	2,334
29	18	3325	1,890	Unk	7,200	Unk	16,808,910	2,335
30	55	3325	6,240	Unk	7,500	64,764	18,050,704	2,407
31	17	3325	4,032	Unk	11,400	Unk	28,475,088	2,498
32	7	3324	4,675	Unk	2,100	16,722	5,364,409	2,554
33	30	3325	4,420	Unk	11,700	39,852	30,156,507	2,577
34	57	3325	7,200	Unk	13,000	96,504	33,517,717	2,578
35	27	3325	8,400	Unk	6,250	71,161	16,526,346	2,644
36	35	3325	2,040	Unk	480	3,790	1,286,880	2,681

Rank	Plant	SIC	Production Hours (hrs/year)	Production Size (sq ft)	Tons of Production (tons/year)	Demand Consumption (kW/year)	Electricity Consumption (kWh/year)	Energy Density (kWh/ton)
37	26	3325	4,000	Unk	915	Unk	2,504,103	2,737
38	9	3324	4,250	Unk	375	Unk	1,034,877	2,760
39	10	3324	4,940	Unk	625	2,904	1,838,218	2,941
40	3	3324	2,080	28,696	500	7,887	1,505,600	3,011
41	44	3325	2,080	Unk	1,500	Unk	5,021,102	3,347
42	24	3325	2,600	Unk	2,500	86,702	9,232,154	3,693
43	32	3325	2,750	Unk	4,000	Unk	15,792,790	3,948
44	11	3325	5,250	240,000	3,300	52,104	16,492,880	4,998
45	53	3325	5,250	Unk	3,300	52,104	16,492,880	4,998
46	47	3325	2,880	Unk	2,822	Unk	14,153,283	5,015
47	5	3324	6,120	Unk	3,500	Unk	18,333,822	5,238
48	8	3324	4,862	Unk	300	Unk	1,638,042	5,460
49	34	3325	2,160	Unk	1,600	Unk	9,117,233	5,698
50	50	3325	6,240	Unk	1,250	27,192	7,188,140	5,751
51	1	3324	6,240	41,000	830	16,815	4,915,101	5,922
52	12	3325	3,120	74,000	1,000	49,143	6,460,800	6,461
53	39	3325	3,120	Unk	1,000	49,143	6,460,800	6,461
54	4	3324	4,000	Unk	950	Unk	8,881,301	9,349
55	22	3325	2,400	Unk	6,000	Unk	61,808,618	10,301
56	16	3325	4,096	Unk	726	Unk	17,505,862	24,113
57	14	3325	8,760	175,225	500	42,023	16,627,747	33,255
58	2	3324	8,595	50,000	500	39,483	16,650,704	33,301
59	45	3325	4,160	Unk	220	Unk	11,016,120	50,073

Information from a total of 20 plants with SIC code 3471 was retrieved from the IAC database. All of these plants were assessed over a 4 year period (2002, 2003, 2004, and 2005). Of these, a total of 20 plants were found to have enough relevant information to conduct a comparison against the metal finishing operations at RIA, CCAD, and TYAD (Table 4).



**Table 4. Metal finishing energy density.**

Rank	Plant	Production Hours (hrs/yr)	Plant Size (sq ft)	Production Size (sq ft)	Electricity Consumption (kWh/yr)	Natural Gas Consumption (MMBTU/yr)	Total Energy Consumption (MMBTU/yr)	Total Adjusted Energy Consumption (MMBTU/yr)	Energy per Sq ft (MMBTU/sq ft)
1	9	4,500	49,500	14,850	2,977,329	620	10,779	8,623	0.58
2	11	2,340	38,000	11,400	780,000	9,045	11,706	9,365	0.82
3	13	7,250	101,538	30,462	5,353,793	13,409	31,676	25,341	0.83
4	8	4,630	8,300	2,490	918,774	8	3,143	2,514	1.01
5	1	4,048	64,350	19,305	4,016,960	10,845	24,551	19,641	1.02
6	14	3,500	25,100	7,530	627,932	7,573	9,716	7,772	1.03
7	20	8,400	250,000	75,000	25,460,672	12,303	99,175	79,340	1.06
8	18	4,800	150,000	45,000	7,028,261	54,000	77,980	62,384	1.39
9	7	5,100	140,000	42,000	5,249,460	73,568	91,479	73,183	1.74
10	12	2,250	49,038	14,712	6,067,279	11,381	32,083	25,666	1.74
11	4	8,400	50,000	15,000	3,898,476	19,569	32,871	26,296	1.75
12	2	2,730	25,000	7,500	1,327,589	12,347	16,876	13,501	1.8
13	CCAD	2,000	61,447	61,447	10,458,816	82,782	118,467	118,467	1.93
14	5	6,120	91,042	27,313	4,536,000	52,554	68,031	54,425	1.99
15	3	4,550	110,000	33,000	4,996,764	68,788	85,837	68,670	2.08
16	TYAD	4,000	60,000	60,000	2,083,000	138,050	145,157	145,157	2.42
17	19	6,000	89,000	26,700	5,940,600	62,051	82,320	65,856	2.47
18	17	2,730	10,000	3,000	657,280	7,485	9,728	7,782	2.59
19	16	4,420	35,000	10,500	2,476,457	27,673	36,123	28,898	2.75
20	15	6,552	18,750	5,625	1,944,960	13,000	19,636	15,709	2.79
21	6	6,000	80,000	24,000	10,118,489	74,581	109,105	87,284	3.64
22	RIA	6,240	55,000	55,000	13,305,140	164,075	209,472	209,472	3.81
23	10	6,240	25,600	7,680	4,171,597	30,862	45,095	36,076	4.7

Information from the IAC database for the metal finishers details their annual energy use in terms of both electricity and natural gas. Electricity is used to electroplate the metal, and to power the supporting equipment in the facility, such as lighting, motors (pumps, fans and drives), compressed air and HVAC. Natural gas, through one or more steam or hot water boilers, is used to provide heat the various metal finishing and rinsing solutions in the tank lines, and to HVAC units that condition the plant. To ensure an accurate comparison, one million British thermal units (MMBTU) were chosen as the common unit for all of the plants and the three arsenals/depots.

The database does not allow isolation of any one particular energy-using system, which means that the energy use of the plating lines cannot be broken out from the energy use of the plant. For example, the energy used to light the warehouse areas cannot be determined, only the energy use of the entire plant. This differs from the energy use as measured at RIA, CCAD and TYAD, which details only the energy use of the metal finishing area. To overcome this, a leveling factor of 80 percent is used to isolate the production energy use from that of the nonproduction areas, such as offices, storage, and maintenance. The assumption is that the production areas of the plants in the IAC database account for 80 percent of the total plant energy use. While not the most precise metric, this leveling factor is the only way to isolate the production energy use of the metal finishing plants taken from the IAC database to establish a better basis for comparison and hence a better benchmark.

Additionally, each of these plants also had a figure detailing the total number of pieces that particular facility electroplated over the year previous to the assessment. Unfortunately, past experience in metal finishing plants indicates that the pieces are wildly variable in both size and surface area. Looking only at car parts, for example, one plant may electroplate door handles and small fittings, generating a large volume of parts annually. A second plant may coat bumpers and body moldings, which are both larger (in size and surface area) and coated in fewer numbers than handles and fittings, resulting in a lower annual volume of production. Comparing these two plants would not be feasible, as the disparity in sizes and surface areas, combined with the differences in annual volume produced, would result in a nearly meaningless comparison.

No way was found to isolate the plating areas of the plants and determine a common unit of comparison. To overcome this, two approaches were used. To overcome the inherent limitations in the IAC database while providing a broad comparison to the industry in general, the energy use per square foot is used as a basis of comparison. While area is a very general unit, it does allow for comparison between the Army facilities in particular against the industrial plants in general. The limitations of this comparison are obvious; a plant may be large in size while being largely unused; there may be larger or smaller warehouse and/or office areas; or a plant may be larger or smaller than average due to a layout that increases or decreases the spacing between tanks. Despite this, the initial energy densities of the

plants, measured in MMBTUs per square foot (MMBTU/sq ft), were calculated and found to offer less variation than originally thought. To decrease the variation further, and to account for the production areas of the facilities as opposed to the warehouse, office and maintenance areas, a leveling factor of 30 percent was applied to the plant areas as provided by the IAC database. The assumption is that the production areas of the plants in the IAC database account for only 30 percent of the total plant size in sq ft. Again, while not the most accurate method, this leveling factor is the only way to isolate the production areas of the plants from the nonproduction areas to establish a better basis for comparison and hence a better benchmark.

The annual energy use (unadjusted) in MMBTU for the plants ranges widely, from 3,100 MMBTU to over 118,000 MMBTU/yr. Plant size ranges from just over 8,000 sq ft to 250,000 sq ft. The energy density of these plants, which compares the annual energy use in MMBTUs against the size of the plant production areas in sq ft, ranges widely. The energy density of these plants ranges from 0.58 MMBTU/sq ft to over 4.7 MMBTU/sq ft. As with the metal casters, there appears to be little correlation between the annual operating hours and plant sizes when compared to the resulting energy densities of the various facilities. There is a broad range of energy densities, and hence energy efficiencies, at these plants. Because of these difficulties, it was decided that a qualitative comparison was best.

#### **4.4.3 Heat Treat**

The IAC database held by CAES at Rutgers University contains 53 reports detailing plants that have a primary Standard Industrial Classification (SIC) code of 3398, which covers plants that are engaged in heat treating of metal, including annealing, brazing (hardening), burning, hardening, shot peening, and tempering of metal for the trade.

Information from a total of 20 plants with SIC code 3398 was retrieved from the IAC database. All of these plants were assessed in the last 7 years (2000-2006). Of these, a total of 12 plants were found to have enough relevant information to conduct a comparison. Further analysis reduced this number to 11 plants, which were then compared against the heat treat operation at RIA and CCAD (Table 5).

**Table 5. Heat treat facility (SIC 3398) energy density.**

Plant	Production Hours (hrs/yr)	Production Size (sq ft)	Tons of Production (tons/yr)	Natural Gas Consumption (MMBTU/yr)	Natural Gas Consumption (kWh/yr)	Electricity Consumption (kWh/yr)	Total Energy Consumption (kWh/yr)	Energy Density (kWh/ton)
9	8,736	150,000	60,000	178,159	608	3,569,510	3,570,118	59
5	6,120	104,061	32,400	228,548	780	4,105,491	4,106,271	127
1	4,800	80,000	5,000	8,926	30	902,822	902,852	181
6	6,120	246,528	21,000	194,691	664	4,460,621	4,461,285	212
2	8,400	192,000	12,500	130,869	447	2,679,540	2,679,987	214
10	3,744	50,000	16,250	26,224	89	3,771,657	3,771,746	232
11	8,736	110,000	40,000	227,015	775	11,128,956	11,129,731	278
7	6,240	26,000	2,000	32,559	111	735,719	735,830	368
4	6,240	16,200	1,000	19,030	65	715,194	715,259	715
3	6,240	20,000	1,906	15,351	52	1,611,823	1,611,875	846
8	6,240	20,000	2,925	20,242	69	3,335,580	3,335,649	1,140

Information from the IAC database for the heat treat plants details their annual energy use in terms of both electricity and natural gas. To ensure an accurate comparison, kilowatt-hours were chosen as a common unit for all of the plants and RIA.

As with the metal casters and metal finishers, the database does not allow isolation of any one particular energy-using system, which means that the energy use of the heat treat furnaces cannot be broken out from the energy use of the plant. This is not so significant with the heat treat facilities, as with the metal casters, as the other energy consuming systems at these types of facilities are rather small when compared to the ovens and furnaces found in these plants. This differs from the energy use as measured at RIA, which details only the energy use of the heat treat area.

Each of these plants also had a figure detailing the total amount of metal that particular facility treated over the year previous to the assessment, measured in tons. The IAC database does not allow the user to isolate the plants by the metals treated, so all of the qualifying plants were used, even though it is almost certain that some (if not several) of them treat nonferrous metals, unlike the heat treat facilities at RIA, which treats ferrous metals almost exclusively.

The annual energy use in kWh for the plants ranges widely, from a little less than 700,000 kWh to over 1.1 million kWh/yr. Production also ranges

widely, from a low of 1,000 tons/yr to nearly 60,000 tons/yr. As a result, the energy density of these plants, which compares the annual energy use in kWh against the annual production in tons, also ranges widely. The energy density of these plants ranges from less than 59 kWh to over 1,140 kWh/ton of metal treated. There appears to be little correlation between the annual operating hours, tons of production and energy consumption (kWh/year) and the resulting energy densities of the various plants. There is a broad range of energy densities, and hence energy efficiencies, at these plants.

These energy densities, along with the supporting energy use and production values for all the plants, are detailed in Table 4. Unfortunately, these energy densities cannot be correlated to those of RIA or CCAD due to the unavailability of the heat treat furnace equipment ratings for key pieces of equipment at RIA and the tons of metal treated at CCAD. The nameplates of the equipment at RIA are for the most part obliterated or missing. An afternoon spent with the two operators at RIA revealed that while they know what type of piece should be processed in what furnace, they do not know the ratings of most of their furnaces. The RIA technical library was consulted, but records for the vast majority of the furnaces and ovens were simply not available.

The situation is the reverse at CCAD, where the furnace and oven nameplates are still on the equipment and quite legible. Unfortunately, accurate records of the amount of metal treated were not available. No historical records that might allow for a basic comparison have been kept, and the operators would not hazard a guess as to the amount of metal treated on any given day, week, month, or year. To their credit, the operators were quite candid in that the amount and size of pieces varied greatly from day to day, and that any guess on their part would not provide any useful information. Because of this situation, a qualitative analysis was conducted.

#### **4.4.4 Painting**

The IAC database held by CAES at Rutgers University contains 35 reports detailing plants that have a primary Standard Industrial Classification (SIC) code of 3479 (Coating, Engraving, and Allied Services, Not Elsewhere Classified), which covers plants that are engaged in: (1) enameling, lacquering, and varnishing metal products; (2) hot dip galvanizing of mill

sheets, plates and bars, castings, and formed products fabricated of iron and steel; hot dip coating such items with aluminum, lead, or zinc; retinning cans and utensils; (3) engraving, chasing and etching jewelry, silverware, notarial and other seals, and other metal products for purposes other than printing; and (4) other metal services, not elsewhere classified.

As can be seen, SIC 3479 contains a diverse array of manufacturing operations, each of which has different energy use profile. Unfortunately this wide array of plant types within one SIC is mirrored in the IAC database. Information from a total of 35 plants with SIC code 3479 was retrieved from the IAC database. All of these plants were assessed in the last 7 years (2000-2006). These plants include aviation engines and airframe parts, sintered metal products, thermal coatings, diamond and diamond-like coatings, polymer coatings, Teflon coated products, powder coating and pressure sensitive adhesives on various substrates. This array is too broad to make a comparison between the IAC facilities and the Arsenal and Depot operations relevant. As such, a quantitative analysis of the Arsenal and Depot paint shops was made.

Tables 7 and 8 list these energy densities, along with the supporting energy use and production values for all the plants.

## **4.5 Metal Casting**

### **4.5.1 Rock Island Arsenal**

Rock Island Arsenal houses the Joint Manufacturing and Technology Center (JMTC), which contains the only remaining U.S. Army foundry. This foundry is the Department of Defense's (DOD's) only metal manufacturing complex that can produce final products from the original raw material.

The systems at the RIA foundry include two Inductotherm induction melting furnaces, one 5-ton furnace and one 3-ton furnace, and six Pillar steel frame induction melting furnaces. Four of these furnaces each have melt capacities of approximately 200 lbs while the remaining two furnaces have melt capacities of approximately 100 lbs each.

Interviews with production and maintenance personnel indicated that these furnaces are only used occasionally, mainly in support of Army contracts but sometimes for outside (non-Army) contracts that the Arsenal

has bid on. On the three occasions that the RIA foundry was visited and assessed, no metal was being melted. Records from the RIA Foundry indicate that the two furnaces were used a total of 89 times in 2005; the 3-ton furnace was used a total of 19 times from January through mid-June, while the 5-ton furnace was used a total of 70 times from April to the end of the year. The 3-ton furnace melted a total of 204,750 lbs of metal, using 66,800 kWh of electricity, while the 5-ton furnace melted a total of 1,626,700 lbs using 533,940 kWh that same year. Examining the electricity per ton, the 3-ton furnace used an average of 653 kWh/ton, while the 5-ton furnace used an average of 656 kWh/ton. The variation of the values within each of the furnaces melting runs was minimal; the average energy per melt is an accurate representation of the overall energy use and efficiency of the furnaces. Because of this and the fact that the foundry has no metering equipment measuring electricity use, electrical measurements of a previous melting job were used to provide a benchmark figure for the foundry. The measurements, obtained by the RIA energy manager as part of a study on melting efficiency, were obtained in 2002 when the foundry was melting decontaminated chemical agent containers and chemical process equipment.

Thermocouples were attached to the 3-ton Inductotherm furnace for the duration of one of the melts, measuring the kilowatt-hours of electricity consumed over the course of the melt. The melt lasted for approximately 2 hours (123 minutes) and had a measured high of 160 kWh. The electricity used decreased gradually over the course of the melt as the metal melted, increasing both as metal was added to the melt and when the furnace was turned off for a period to add an oxygen lance. Over the last twenty minutes of the melt the furnace drew approximately 50 kWh until being turned off.

At the end of the melt, which lasted 123 minutes, the 3-ton furnace had drawn a total of 2,090 kWh to melt 2 tons of metal. Taking the energy and dividing by the total amount of metal melted results in an energy density of 1,045 kWh/ton. This number represents the best efficiency that the 3-ton furnace at the RIA foundry can expect to obtain; the average efficiency of the 3-ton furnace, and probably the foundry as a whole, is most likely lower. However, this number does allow the RIA foundry to be compared to comparative operations in the private sector.



The energy densities of the industrial metal casters, and the RIA foundry, along with the supporting energy use and production values for all the plants, are detailed in Table 3.

#### **4.5.2 Energy Use at the RIA Foundry**

As can be seen from the table, the energy density at the RIA foundry ranks 2<sup>nd</sup> lowest of the 59 metal casters benchmarked in this study, with an energy density of 656 kWh/ton. The median rank is 30, and the median energy density is 2,407 kWh/ton. The RIA foundry ranks in the first 25th percentile, which is 1,807 kWh/ton or lower.

RIA is ranked 45th of the 59 facilities in terms of tons of metal melted per year, approximately the bottom quartile, making it below average in terms of output. While RIA has only 3 percent of the metal output of the largest melter, its production is over four times that of the smallest producer and three times that of the next largest producer. As a general rule, the more metal melted per year the more efficient a plant is in terms of energy efficiency; the smaller plants are less efficient than the larger plants when comparing the groups. However, considering only the plants that melt less than 1,000 tons of metal per year, RIA ranks first in terms of efficiency.

#### **4.5.3 Metal Casting Operations and Procedures**

Note that this number represents the energy efficiency of a single melt on a single furnace at the RIA foundry. It is probable that the overall efficiency of both the furnace and the foundry itself is less than the energy density indicated. There is a plant with energy use less than that of the Arsenal foundry, which indicates that there is a more efficient facility than RIA in full operation. Even so, if the energy density of the RIA foundry were found to be twice that indicated, the operation would rank 24th of the 59 facilities, a level that is greater than the 25th percentile, but still less than the median value.

While specific conclusions should not be drawn, some inferences can be made about the low energy density of the RIA foundry. First, it is known that the RIA foundry has far fewer jobs and hence works far fewer hours per year than any most if not all of its industrial counterparts, even if the actual number of annual operating hours is unknown. Fewer jobs increases the time between melts, which in some cases may mean that the

furnaces are kept on, but in most cases means that they are shut down until the next job.

This is in contrast to the industrial facilities, which may keep furnaces on and metal molten between jobs because it requires less energy than letting the furnaces grow cold and then having to get them up to temperature. While this method uses less energy than turning off the furnaces, it is still inefficient. If a facility does this a number of times or adopts the practice as an operating pattern, it is operating more efficiently than if it chose the next best option, but it is still consuming an enormous amount of energy.

Second, having fewer jobs and shutting down the furnaces between them results in less use of the supporting systems, such as compressed air, HVAC and lighting. As the RIA foundry is largely unused between jobs, the secondary systems see little use as well, resulting in less energy use. While not significant compared to that of the melting furnaces, the energy use of these systems is significant in itself. Turning them off for long periods of time increases the foundry efficiency and decreases the energy density per ton of metal.

Note that the RIA foundry has an enormous advantage in that: (1) it does not have to operate continuously in response to jobs, increasing efficiency, and (2) its primary purpose is to be ready to start operations quickly and to support mission requirements, not to show a profit. This is in marked contrast to the industrial foundries, which must show a profit to stay in business, retain its workforce, and remain competitive in the market place. These are secondary concerns to RIA, which allow it a greater degree of freedom in conducting its operations.

Finally, having fewer jobs results in better support of and greater attention being paid to those jobs. Equipment is operated efficiently, maintenance is scheduled and conducted regularly, and there is less confusion and greater communication, leading back to more efficient equipment operation. In terms of labor practices this is probably inefficient and could not be sustained in private industry, but in terms of energy the effect is to improve operating efficiency.

## **4.6 Metal Finishing**

### **4.6.1 Rock Island Arsenal**

RIA has an extensive metal finishing facility where chrome plating, cadmium plating, copper plating, phosphate coating, and anodizing are performed. The facility is approximately 55,000 sq ft in size and is located within the JMTC.

The RIA metal finishing facility has a number of natural gas and electric systems supporting its operation. These systems include the Arsenal's central coal boiler plant and steam distribution system; heat exchangers; scrubber, fan, pump and make-up air unit (MAU) motors; lighting; rectifiers; and compressed air. These systems are not submetered or monitored for energy consumption so their annual energy use had to be calculated.

The annual energy use for these systems was calculated from data and information gained over the course of three visits to the RIA metal finishing facility. For each of the systems, nameplate data, information from technical drawings and schematics, and personnel interviews were used to determine the power and energy used. Annual operating hours were then calculated and applied, and usage times, usage factors, efficiency factors, to determine the annual energy use of each system. Finally, the usages were totaled and converted to a common unit.

The RIA metal finishing facility's electrical systems use a total of 13.3 million kWh of electricity per year. The natural gas systems use a total of 164,000 MMBTUs of natural gas per year. After conversion of units, the total of the two types of energy results in 209,000 MMBTUs of energy used by the RIA metal finishing facility per year.

Table 4 (p 91) lists the energy use and energy density of the RIA metal finishing facility.

### **4.6.2 Corpus Christi Army Depot**

Corpus Christi Army Depot (CCAD) operates a new metal finishing facility, one of the most advanced metal finishing facilities in the Department of Defense. The new metal finishing facility consists of 18 process lines with 25 processes including electroplating, conversion coating, anodizing, metal

stripping, aqueous cleaning, passivation, aluminum vacuum coating, nitrogen implantation, stress relief, and organic finishing. The CCAD metal finishing facility is approximately 61,000 sq ft in size and is located in its own structure immediately adjacent to the CCAD main industrial complex (Building 8).

Like the RIA metal finishing operation, the CCAD facility has a number of systems supporting its operation. These natural gas and electrical systems include local natural gas boilers and corresponding steam distribution system; electrical immersion heaters; scrubber, blower, fan, mixer, agitation, pump and air make-up unit (AMU) motors; lighting; rectifiers; and compressed air. Despite the newness of the facility, these systems are not sub-metered or monitored for energy consumption in any way, so their annual energy use had to be calculated.

The annual energy use for these systems was calculated from data and information gained over the course of one visit to the CCAD metal finishing facility conducted over a period of 5 days. For each of the systems, name-plate data, information from technical drawings and schematics, and personnel interviews were used to determine the power and energy used. As with the RIA metal finishing facility, annual operating hours were then calculated and applied, and usage times, usage factors, efficiency factors, to determine the annual energy use of each system. The usages were then totaled and converted to a common unit.

Corpus Christi Army Depot's metal finishing facility's electrical systems use a total of 10.4 million kWh of electricity per year. The natural gas systems use a total of nearly 83,000 MMBTUs of natural gas per year. After conversion of units, the total of the two types of energy results in 118,000 MMBTUs of energy used by the CCAD metal finishing facility per year.

Table 4 (p 91) lists the energy use and energy density of the CCAD metal finishing facility.

#### **4.6.3 Tobyhanna Army Depot**

Tobyhanna Army Depot built a new Industrial Operations Facility (IOF) in 1998. Included within the IOF is a state of the art metal finishing facility. Processes supported at the TYAD metal finishing facility include chromate

conversion coating, zinc phosphate, acid cadmium, hard coat anodizing and sulfuric acid anodizing; nickel plating and electroless nickel plating; noncyanide copper and silver plating; steam cleaning and ultrasonic cleaning; and black oxide coating. The TYAD metal finishing facility, housed in the IOF, is approximately 60,000 sq ft in size.

The TYAD metal finishing facility has a number of systems supporting its operation. These natural gas and electrical systems include district natural gas boilers and supporting steam distribution system; scrubber, blower, fan, mixer, and pump motors; lighting; rectifiers; and compressed air. Individually, these systems are not submetered or monitored for energy consumption, but the metal finishing facility as a whole is metered and measured, as are other major portions of TYAD.

The TYAD metal finishing facility's electrical systems use a total of 2.1 million kilowatt-hours of electricity per year. The natural gas systems use a total of 138,000 MMBTUs of natural gas per year. After conversion of units, the total of the two types of energy results in 145,000 MMBTUs of energy used by the TYAD metal finishing facility per year.

Table 4 (p 91) lists the energy use and energy density of the TYAD metal finishing facility.

#### **4.6.4 NADEP, San Diego**

Naval Aviation Depot (NADEP), North Island, one of only three aerospace industrial depots in the Department of the Navy, employs over 3,000 military and civilian personnel in over 70 buildings. The plating shop at NADEP San Diego supports the plating and cleaning operations for a variety of aircraft and associated systems and components.

#### **4.6.5 Energy Use by the Metal Finishers**

The energy density at the three Arsenal/Depots rank in the lower 50th percentile of metal finishers benchmarked in this study (Table 3). The energy densities of the U.S. Army facilities is 1.93 MMBTU/sq ft, 2.42 MMBTU/sq ft, and 3.81 MMBTU/sq ft for CCAD, TYAD and RIA, respectively.

The CCAD metal finishing facility ranks 13th, the TYAD facility 16th, and the RIA metal finishing area 22nd of 23 total plants benchmarked. The median rank is 12, and the median energy density is 1.80 MMBTU/sq ft. The CCAD and TYAD metal finishing facilities rank between the 50th and 75th percentiles, while the RIA plant ranks second to last of all the facilities, between the 90th and 100th percentiles.

#### **4.6.6 Metal Finishing Operations and Procedures**

While at first glance it appears that the Arsenals/Depots are not performing and their industrial counterparts, there are a number of factors that must be taken into account before any conclusions are made.

First, the Arsenals/Depots often do not know what parts and assemblies they will be processing any particular day. While there is a plan on what will be brought to the metal finishing shop and when, these plans are subject to constant and frequent change and are followed less often than generally thought. The RIA metal finishing shop was very direct when they said “We sometimes do not know about an order until it shows up that morning.”

To counter this situation of constant change, the Arsenal/Depot metal finishing shops to lesser or greater degree ensure that all of their tanks are fully heated and ready to process parts all of the time. While this allows great flexibility in terms of functionality and ability to respond to changing events, it dramatically increases the energy use of the Arsenal/Depot facilities. This is in comparison to the industrial metal finishers, who also have their tanks fully heated every day, but in preparation for scheduled jobs whose parts and assemblies are in-house and ready to begin processing. It is the job of the industrial metal finishers to ensure that they have jobs on a daily basis to maintain profitability, a driver that is not a primary concern to the Arsenal/Depot metal finishers, who are subject to the overall planning of the Arsenal/Depot.

When the jobs are completed, the industrial metal finishers shut their tanks and supporting systems off for the day, even if it is only half to three quarters through the shift. The industrial metal finishers can do this because they have full control over their schedules and know if there is an order ready for processing or not. Again, this is in comparison to the Arsenal/Depot metal finishers, who often do not shut their equipment off as

they never know when a last minute, rush order will appear, one that is expected in the next shop immediately after processing. This situation also increases the energy use of the Arsenal/Depot metal finishers in comparison to their industrial counterparts.

Another difference between the Arsenals/Depots and their industrial counterparts is the government facilities reliance on legacy systems to power their operations. The RIA and TYAD metal finishing facilities rely on district heating systems to provide heat to their tanks. District heating systems are less efficient than local heating systems, such as boilers, contributing to the overall difference in energy use between the two types of operations. Also, the RIA district heating system is driven by a coal-fired boiler that, although kept up and improved, was constructed in 1917. The steam distribution system for RIA is of more recent vintage, having been constructed in 1945. Newly constructed bituminous coal-fired plants (similar to RIA's plant) can achieve efficiencies of 45 to 47 percent using currently developed materials; the efficiency of the RIA boiler plant is certainly less. Taking the entire system into account, the RIA steam distribution steam distribution arrangement has an efficiency in the range of 22 to 27 percent, far less than the 44 percent efficiency that can be achieved with a local heating system.

The air compressors supporting the metal finishing operation at RIA are from another legacy system that must be accounted for when comparing energy efficiency. The six reciprocating compressors in Building 220 are mostly of older vintage. The three Worthington units were constructed in 1917, 1919, and 1941. The three Ingersoll-Rand units are newer, having been built in 1951, 1953, and 1985, respectively. These units are regarded by both the operators and maintenance personnel at RIA as highly reliable, which is why they have not been replaced by newer units. They are also, without question, less efficient than newer counterparts that have been manufactured in the past 10 years. RIA upgraded its air compressors in 1992, but found that the new units were not as reliable as their legacy air compressors. The new units now support nonessential operations and RIA has returned to having its older units support primary operations.



#### **4.6.7 Areas of Opportunity**

An area where the Arsenal and Depots could improve their metal finishing operations is in adopting energy recovery ventilation to recover heat exhausted from the metal finishing spaces before it is vented to the atmosphere. While CCAD cannot take full advantage of this opportunity, both RIA and TYAD experience cold winters over relatively long periods of time and so could benefit from this measure.

Additionally, all of Arsenal and Depots could better control their HVAC systems and tie them into either building automation or better match their operation to that of production.

Arsenal and Depot metal finishing operations that are dependent on steam heating, in this case RIA, TYAD, and CCAD, should eventually consider the installation of induction heaters to replace their steam system. Steam heating is very inefficient as compared to induction heating, and the increasing price of natural gas will make this more attractive as time goes by.

Finally, all of the Arsenal and Depots should consider the installation of turbulators/impellers to agitate the fluids in the tanks, replacing motors driving fans or mixers, steam bubbling, or compressed air. Turbulators offer significant energy savings as they dramatically reduce the size of the motor needed to agitate the solutions or reduce the need for compressed air.

#### **4.6.8 Areas of Energy Efficient Practices**

A number of energy efficient practices adopted by the Arsenal/Depots have greatly reduced their energy consumption and offset the increased usage due to changes in planning and legacy systems.

#### **4.6.9 Energy Practices**

The first is the adoption of high efficiency motors. The Arsenal/Depots almost without exception have adopted high and premium efficiency motors for applications that require the application of high horsepower over long periods of time. This describes very well the fans, HVAC and scrubber systems used by the metal finishing operations at all three facilities. When motors burn out, energy efficiency is taken into account when repair and

replacement decisions are made. High and premium efficiency motors are more energy efficient than their standard efficiency counterparts. The 1 to 4 percent difference in efficiency can result in millions of kilowatt-hours savings over the life of the motors. This is in comparison to the industrial metal finishers, who for the most part look at first (initial) costs as the determinant in making motor repair and replacement decisions.

Additionally, the Arsenal/Depots have adopted VFDs for some motor applications. Many electric motor-driven devices operate at full speed even when the loads they are serving are less than their capacity. To match the output of the device to the load, some sort of part load control is in use for the majority of their life. Examples include pumps, fans, and HVAC equipment, all of which are common to metal finishing facilities.

The most efficient method of part load control, resulting in minimal wasted energy, is the variable frequency drive. VFDs accomplish part load control by varying electric motor speed. Energy savings of 50 percent or more are common. The Arsenal/Depots have been found to have adopted VFDs more often than their industrial counterparts. This may be due to the high cost of VFDs for larger motors, where they pay back quickest, or it may be due to the resources that the Arsenal/Depots can call on to calculate the savings achievable with advanced mechanical systems, an advantage they have over their industrial counterparts.

Finally, and without exception, the Arsenal/Depots have adopted high-efficiency lighting. While the savings are small as compared to heating and motor systems, over time they can account for several tens of thousands of kilowatt hours, reducing energy use in increasing energy efficiency.

NADEP San Diego has implemented several environmental demonstration projects of note that have energy conservation components. The NADEP chrome plating shop currently uses five chrome plating tanks with “push-pull” air ventilation systems and a related outdoor air pollution control device that operates continuously to minimize chrome emissions. The system requires no continual ventilation for zero chrome emissions to the environment and meets stringent personnel exposure requirements set by OSHA. This technology, in addition to reducing environmental emissions, also reduces the amount of heat exhausted from the building during the (brief) heating season periodically experienced by San Diego. This project

can be replicated at other DOD facilities and would realize significant heating savings if installed in an Arsenal or Depot with a long heating season.

The plating shop at NADEP San Diego has also started to retrofit some of its tanks with turbulators that will replace an energy intensive air bubble system. The new mixing system uses the fluid pumped through eductors at the bottom the tanks for more effective mixing. These eductors are more energy efficient than driving fans or mixers, steam bubbling, or compressed air and can be installed in other plating shops.

Finally, NADEP San Diego has been installing new, automated plating covers on some of its larger plating tanks. This cover is being demonstrated as a retrofit the entire shop that, once fully installed, will allow ventilation for the entire plating operation to be turned down when the tanks are not in use, resulting in significant energy savings. This technology is also being used at Boeing Aircraft in Washington State.

## **4.7 Heat Treat**

### **4.7.1 Rock Island Arsenal**

Heat treating capabilities at RIA include annealing, hardening, tempering, and surface carburizing. Nearly 50 furnaces and ovens are housed in the facility, organized into three general lines, most of which are Layed Away In Place (LIP). This equipment is shut down and locked out in its current location with proper documentation. This practice of locking out the equipment not only saves thousands of dollars in removal costs, but eliminates the reinstallation, setup, and calibration costs should it ever be needed to be placed back in operation.

Before the LIP program, RIA designed and modified some of its existing furnaces in the heat treat shop by upgrading the facility with construction of an afterburner and stack monitoring equipment. This was done to heat treat 4,000 decontaminated chemical agent containers and 1,800 tons of process equipment in preparation for recycling. With an organic manufacturing system, RIA has a highly versatile and fully integrated foundry and machine shop, along with an on site pattern shop that allows it to transform engineering drawings, data, and information into fully designed products.

The ovens and furnaces at the RIA heat treat facility are both electricity and natural gas powered, and the facility has a number of natural gas and electric systems supporting its operation. These systems include the Arsenal's central coal boiler plant and steam distribution system, which is used for space conditioning; lighting; motors; and compressed air.

#### 4.7.2 Corpus Christi Army Depot

The heat treat facility at CCAD is much smaller than its counterpart at RIA, containing 14 furnaces, only 11 of which are being used. All 14 furnaces are powered by electricity and range in size from 40 kW to 300 kW. Table 6 lists the metrics available for the RIA and CCAD heat treat facilities. Note that the data in Table 6 reflect estimates of the energy usage at RIA and CCAD heat treat facilities. Since these facilities do not track their production hours, tons of production, or their energy consumption for either electricity or natural gas, their estimated energy use is listed separately from the measured data on the private facilities (in Table 5).

**Table 6. Metrics for Army heat treat facilities.**

Arsenal/Depot	Estimated Rated Load (kW)	Estimated Usage Factor	Annual Energy Usage (MMBTU)
CCAD	1,353	0.75	1,440
RIA	3,080	0.75	3,279

#### 4.7.3 Energy Use by the Heat Treat Facilities

Energy use by the heat treat facilities falls into five major categories of equipment. These are lighting, motors, compressed air, HVAC and the furnaces and ovens. Of these, the furnaces and ovens form the bulk of the energy use, while the remaining systems are relatively insignificant users.

#### 4.7.4 Heat Treat Operations and Procedures

Unlike the metal finishing and painting facilities, the RIA and CCAD heat treat shops know what parts will be arriving on any given day and for the most part know the time of their arrival. This may be due to the fact that heat treat operations must be conducted after certain operations but before others and cannot be moved around in the sequence of operations. It can be argued that painting should be similar to heat treat in this way, but it appears that the variability associated with painting has to do with other operations finishing sooner than expected rather than movement by parts

within the sequence of operations. Metal finishing of parts is so variable because the tanks are for the most part ready at almost any time to start plating, which is not the case with painting and especially heat treat. Additionally, metal finishing can occur at most points within the sequence of operations, especially if the parts are being plated only cover a portion of their surfaces.

The only systems that appear to kept operating in expectation of heat treat operations are the area lights, which were observed to be on at nearly all times at both RIA and CCAD, whether heat treat of parts was occurring or not. In the RIA heat treat shop the space was conditioned whether heat treat was being done, and the compressed air lines were energized as well.

#### **4.7.5 Areas of Opportunity**

The heat treat facilities can take advantage of a number of opportunities available to reduce energy use. First, they can turn off high bay lighting fixtures when heat treat operations are not being conducted. A number of HID fixtures can be turned off in this manner, especially at RIA, which has a large heat treat facility that is kept fully illuminated during production hours.

As with the metal finishing operations, an area where RIA could reduce its energy use is in adopting energy recovery ventilation to recover heat exhausted from the heat treat spaces before it is vented to the atmosphere. While CCAD cannot take full advantage of this opportunity, RIA experiences cold winters over relatively long periods of time and so could benefit from this measure.

#### **4.7.6 Areas of Energy Efficient Practices**

For the most part the heat treat shops have adopted energy efficient high bay lighting to provide general illumination. This lighting reduces energy use by the facilities and provides the quality light necessary in painting applications. CCAD still has some scattered installations of low pressure sodium lights, which is moderately efficient but produces poor light for illuminating tasks.

## **4.8 Painting**

### **4.8.1 Rock Island Arsenal**

The RIA spray paint area located in the Building 208 is capable of applying CARC (chemical agent resistant coatings). Other painting capabilities include production painting, camouflage and powder paint. The painting operation at RIA has three paint booths and a drying booth. The RIA painting facility has a number of natural gas and electric systems supporting its operation. These systems include the Arsenal's central coal boiler plant and steam distribution system; fan and make-up air unit (MAU) motors; lighting; and compressed air.

### **4.8.2 Corpus Christi Army Depot**

Painting at CCAD takes place in four locations. Helicopter fuselages are painted in one of the four booths located in Building 1808. Engines and transmissions are painted in booths located in southern end of Building 8. Fuselage parts and other parts are painted in the northern end of Building 8. Small accessory parts are painted in the lower level of Building 340. The spray booths are either a side draft type that are open on one side where the painter stands or are enclosed with a downdraft exhaust. No ovens are used to facilitate drying.

The parts are often large and difficult to handle thus they are often placed on tables for painting. The enclosed booths are large enough to accept the entire helicopter with the largest having an approximate size of 30 ft wide by 75 ft long by 30 ft high. To achieve a greater painting capacity a new paint shop is planned for the site. This painting facility will replace the helicopter fuselage painting in Building 1808 and the painting in the northern side of Building 8.

### **4.8.3 Sierra Army Depot**

Building 210 is used for painting vehicles, trailers, and other equipment of various types and size. The building has two paint booths; one small booth with one paint line and one much larger booth with six paint lines. The spray paint area located in the Building 210 is capable of applying chemical agent resistant coatings (CARC). Two more paint booths have been ordered for Building 210 to meet the increased production needs at SIAD.

#### **4.8.4 Tobyhanna Army Depot**

TYAD has state-of-the-art painting facilities located in Building 1E large enough to handle 40-ft trailers. Paint booths are available to accommodate any items being coated or refinished. Some paint booths have the capability to paint and bake finished items. Table 7 lists the energy use of painting facilities in the IAC database, and Table 8 details the energy use per unit produced, plant area (sq ft) and plant production hour. Table 9 lists the metrics available for the Arsenal and Depot painting facilities.

Note that the data in Table 9 reflect estimates of the energy usage at the selected painting facilities. DOD facilities do not track annual production, or energy consumption for either electricity or natural gas. Additionally, the sizes of the DOD facilities vary greatly due to the size of the parts and equipment they paint. A metric based on energy usage per square foot would provide an unrealistic basis of comparison between DOD and private facilities. Therefore, the data pertaining to DOD facilities are listed separately to highlight the differences between them and the private facilities.

#### **4.8.5 Energy Use by the Paint Facilities**

Energy use by the painting facilities falls into four major categories of equipment. These are lighting, motors, compressed air, and HVAC. Of these, motors and HVAC form the bulk of the energy use, while lighting and compressed air are relatively insignificant users.

#### **4.8.6 Painting Operations and Procedures**

Like the metal finishing facilities, the Arsenal and Depot paint facilities often do not know what parts and assemblies they will be painting any given day. This is more of a problem for the smaller paint shops at all of the Arsenals and Depots than at the larger painting hangars at CCAD, where it is quite difficult to switch the schedule of painting a large helicopter fuselage. Even so, there is a lot of variance in the schedules that is common to all of the Arsenals and Depots.



**Table 7. Energy use of plants in SIC 3479.**

Number	Report	Principal Product	Annual Production	Plant Area (sq ft)	Annual				
					Production Hours	Electricity (kWh)	Natural Gas (MMBTU)	Total Energy (MMBTU)	Total Energy Cost (\$)
1	WV0326	Metal Plated Products	18,000,000	69,500	2,860	1,550,797	25,088	30,379	\$302,846
2	WV0323	Lined-Pipes & Fittings	400,000	100,000	2,860	1,446,348	6,609	11,544	\$135,248
3	LL0230	Pipe Coatings	70,000	50,000	4,992	1,309,680	52,098	56,567	\$504,075
4	IA0370	Aviation Engines & Airframe Parts	26,000	100,000	4,875	8,930,280	25,740	56,210	\$767,182
5	AM0478	Valve Repair & Coatings	15,000	159,800	5,184	3,328,526	7,649	19,006	\$333,070
6	WI0474	Sintered Metal Products	40,000,000	190,000	8,640	24,705,972	0	84,297	\$1,016,538
7	UD0697	Electroplating & Metal Finishing	120,700	42,000	2,040	671,880	6,587	8,879	\$116,402
8	MS0252	Electrostatic Coatings	98,600	98,600	6,000	4,126,800	13,993	28,074	\$337,432
9	MA0562	Thermal Coatings	108,000	30,000	4,420	2,081,800	2,530	9,633	\$224,137
10	MA0560	Thermal Coatings	168,000	65,000	4,420	4,505,090	26,274	41,645	\$682,643
11	LE0186	Galvanized Steel Products	22,500	60,000	4,160	971,176	36,562	39,876	\$401,757
12	LE0177	Diamond & Diamond-like Industrial Coatings	Unknown	26,000	6,240	3,866,255	1,792	14,984	\$303,277
13	BD0266	Thermal Sprays	40,000	65,000	6,240	2,216,107	6,330	13,891	\$209,041
14	AS0368	Wire Mesh Products	1,224,000	80,000	4,182	971,591	13,344	16,659	\$238,358
15	UM0238	Painted Automobile Parts	36,000,000	70,000	3,500	3,319,405	48,762	60,088	\$501,863
16	UM0229	Coating Automotive Parts	Unknown	486,530	2,280	1,585,061	3,514	8,922	\$209,559
17	UD0671	Coated Steel Products	174,722	231,418	6,000	11,873,586	363,722	404,235	\$2,112,936
18	OK0674	Galvanized Steel Products	8,000	30,000	4,160	485,460	77,422	79,078	\$384,415
19	MS0225	Galvanized Steel	600,000,000	220,000	8,760	32,009,543	306,600	415,817	\$2,662,434
20	MA0544	Metal Finishing	Unknown	20,000	4,250	306,919	7,815	8,862	\$122,001

Number	Report	Principal Product	Annual Production	Plant Area (sq ft)	Annual				
					Production Hours	Electricity (kWh)	Natural Gas (MMBTU)	Total Energy (MMBTU)	Total Energy Cost (\$)
21	CO0505	Galvanized Steel Parts	8,400	30,900	6,240	318,320	25,302	26,388	\$141,554
22	WV0208	Industrial Coating & Pipe Wraps	285,600	44,329	3,060	743,493	5,887	8,424	\$264,814
23	SU0106	Electroplated & Anodized Parts	100,000,000	57,000	6,240	52,539	70,747	70,926	\$425,084
24	SF0213	Hot-Dip Galvanizing	Unknown	16,000	3,669	495,306	27,005	28,695	\$196,022
25	LE0110	Polymer Coatings	500	28,000	4,576	427,742	21,368	22,827	\$133,270
26	IC0007	Teflon Coating Products	250,000,000	28,000	5,486	1,027,803	10,036	13,543	\$154,600
27	UL0245	Electroplated Parts	8,172,500	48,000	6,000	2,225,675	511	8,105	\$97,865
28	UL0242	Powder Coating Parts	32,400,000	40,000	7,488	2,825,323	5,437	15,077	\$189,493
29	SD0245	Metal Plating	50,000	11,100	2,125	208,968	1,414	2,127	\$57,999
30	NV0161	Metal Coating	1,750,000	48,000	4,992	526,071	10,556	12,351	\$104,747
31	MA0466	Powder Coating	250,000	83,000	4,160	740,329	17,962	20,488	\$201,011
32	MA0459	Pressure Sensitive Adhesives on Various Substrates	Unknown	44,000	2,142	470,692	21,012	22,618	\$131,572
33	DS0154	Electrocoat & Powder Coat Painting	1,988,000	10,000	3,432	1,108,735	8,879	12,662	\$110,035
34	CO0459	Fuser Rollers & Parts	1,500,000	52,000	8,112	4,080,306	3,022	16,944	\$195,294
35	AM0383	Hot-Dip Galvanizing	15,000,000	60,000	5,600	43,376	8,414	8,562	\$53,522

**Table 8. Energy use of plants per various metrics in SIC 3479.**

Number	Report	Principal Product	Annual Production	Plant Area (sq ft)	Annual		Energy per Unit (MBTU/Unit)	Energy per sq ft (MBTU/SF)	Energy per Production Hour (MBTU/hr)
					Total Energy (MMBTU)	Total Energy Cost (\$)			
29	SD0245	Metal Plating	50,000	11,100	2,127	\$57,999	42.5	192	1,001
27	UL0245	Electroplated Parts	8,172,500	48,000	8,105	\$97,865	1	169	1,351
35	AM0383	Hot-Dip Galvanizing	15,000,000	60,000	8,562	\$53,522	0.6	143	1,529
28	UL0242	Powder Coating Parts	32,400,000	40,000	15,077	\$189,493	0.5	377	2,013
20	MA0544	Metal Finishing	Unknown	20,000	8,862	\$122,001	Unknown	443	2,085
34	CO0459	Fuser Rollers & Parts	1,500,000	52,000	16,944	\$195,294	11.3	326	2,089
9	MA0562	Thermal Coatings	108,000	30,000	9,633	\$224,137	89.2	321	2,179
13	BD0266	Thermal Sprays	40,000	65,000	13,891	\$209,041	347.3	214	2,226
12	LE0177	Diamond & Diamond-like Industrial Coatings	Unknown	26,000	14,984	\$303,277	Unknown	576	2,401
26	IC0007	Teflon Coating Products	250,000,000	28,000	13,543	\$154,600	0.1	484	2,469
30	NV0161	Metal Coating	1,750,000	48,000	12,351	\$104,747	7.1	257	2,474
22	WV0208	Industrial Coating & Pipe Wraps	285,600	44,329	8,424	\$264,814	29.5	190	2,753
5	AM0478	Valve Repair & Coatings	15,000	159,800	19,006	\$333,070	1,267.10	119	3,666
33	DS0154	Electrocoat & Powder Coat Painting	1,988,000	10,000	12,662	\$110,035	6.4	1,266	3,689
16	UM0229	Coating Automotive Parts	Unknown	486,530	8,922	\$209,559	Unknown	18	3,913
14	AS0368	Wire Mesh Products	1,224,000	80,000	16,659	\$238,358	13.6	208	3,984
2	WV0323	Lined-Pipes & Fittings	400,000	100,000	11,544	\$135,248	28.9	115	4,036
21	CO0505	Galvanized Steel Parts	8,400	30,900	26,388	\$141,554	3,141.40	854	4,229
7	UD0697	Electroplating & Metal Finishing	120,700	42,000	8,879	\$116,402	73.6	211	4,353

Number	Report	Principal Product	Annual Production	Plant Area (sq ft)	Annual		Energy per Unit (MBTU/Unit)	Energy per sq ft (MBTU/SF)	Energy per Production Hour (MBTU/hr)
					Total Energy (MMBTU)	Total Energy Cost (\$)			
8	MS0252	Electrostatic Coatings	98,600	98,600	28,074	\$337,432	284.7	285	4,679
31	MA0466	Powder Coating	250,000	83,000	20,488	\$201,011	82	247	4,925
25	LE0110	Polymer Coatings	500	28,000	22,827	\$133,270	45,654.90	815	4,989
24	SF0213	Hot-Dip Galvanizing	Unknown	16,000	28,695	\$196,022	Unknown	1,793	7,821
10	MA0560	Thermal Coatings	168,000	65,000	41,645	\$682,643	247.9	641	9,422
11	LE0186	Galvanized Steel Products	22,500	60,000	39,876	\$401,757	1,772.30	665	9,585
6	WIO474	Sintered Metal Products	40,000,000	190,000	84,297	\$1,016,538	2.1	444	9,757
32	MA0459	Pressure Sensitive Adhesives on Various Substrates	Unknown	44,000	22,618	\$131,572	Unknown	514	10,559
1	WV0326	Metal Plated Products	18,000,000	69,500	30,379	\$302,846	1.7	437	10,622
3	LL0230	Pipe Coatings	70,000	50,000	56,567	\$504,075	808.1	1,131	11,331
23	SU0106	Electroplated & Anodized Parts	100,000,000	57,000	70,926	\$425,084	0.7	1,244	11,366
4	IA0370	Aviation Engines & Airframe Parts	26,000	100,000	56,210	\$767,182	2,161.90	562	11,530
15	UM0238	Painted Automobile Parts	36,000,000	70,000	60,088	\$501,863	1.7	858	17,168
18	OK0674	Galvanized Steel Products	8,000	30,000	79,078	\$384,415	9,884.80	2,636	19,009
19	MS0225	Galvanized Steel	600,000,000	220,000	415,817	\$2,662,434	0.7	1,890	47,468
17	UD0671	Coated Steel Products	174,722	231,418	404,235	\$2,112,936	2,313.60	1,747	67,372

**Table 9. Energy use per production hour for Army painting facilities.**

Arsenal/Depot	Annual Production Hours (hr/yr)	MBTU/Production Hour	Electricity Use (kWh/yr)	Energy Use (MMBTU/yr)
RIA	8,760	905	2,324,000	7,930
CCAD	2,080	3,908	2,383,000	8,130
SIAD	8,395	393	967,000	3,300
TYAD	2,480	2,330	1,694,000	5,780

To ensure that they are ready to paint with short notice, the smaller facilities have become accustomed to keeping the HVAC equipment supporting painting (as opposed to HVAC equipment supporting space conditioning) operating during across the entire production day instead of during actual painting of parts, assemblies, and equipment. The same is true of lighting associated with painting of both the fixtures in the booths and the overhead bay fixtures that provide general illumination. The lights are kept on during all operating hours, not just painting hours. While it can be argued that some or all of the high bay fixtures must be kept on for general illumination, no such argument can be made for the fixtures, usually 4-ft fluorescent T-12 or T-8 lamps, need be kept on.

#### **4.8.7 Areas of Opportunity**

The painting facilities can take advantage of a number of opportunities available to reduce energy use. First, they can turn off fixtures within the paint booths when painting is not actively being conducted. A number of T-12 and T-8 fixtures can be turned off in this manner. Additionally, the T-12 fluorescent lamps using magnetic ballasts in these fixtures should be replaced with more energy efficient T-8 fluorescent lamps using electronic ballasts. This action will reduce energy consumption without reducing the lumen levels within the booths. Additionally, because T-8 lamps cost less than their T-12 counterparts and in some cases have longer lamp lives, the amount of labor that must be dedicated to changing lamps out will be reduced, and the investment cost in the lamps themselves. There are shatterproof sleeves available for T-8 lamps just as there are sleeves for T-12 lamps; these sleeves do not interfere with the illumination of the area and can be placed on and taken off the T-8 lamps that can be installed in the fixtures just as easily as the current sleeves on the T-12s. Finally, T-8 lamps are more environmentally friendly than T-12 lamps and will help reduce the amount of hazardous mercury that the Arsenals and Depots will have on site.

Similarly, portions of the high bay lighting can be turned off when the paint booths are not conducting operations. Turning a portion of the lights off will provide sufficient illumination for personnel to safely navigate the room while at the same time reducing energy use.

Motors are another area where the painting facilities can take advantage of energy conservation advances. Where the metal finishing shops have adopted VFDs in portions of their HVAC equipment, very few VFDs are found in HVAC equipment contained in the painting facilities. Many electric motor-driven devices operate at full speed even when the loads they are serving are less than their capacity. In the painting facilities, this is often true of the motors driving the HVAC equipment. When no painting is being conducted, the need for outside air is less, but the motors often continue to operate at full speed. Adopting VFDs can allow the painting facilities to reduce their electrical energy use and lower their demand.

The painting facilities can also reduce plant wide electrical energy use by reducing the air pressure of the compressed air used for painting. Many plant air compressors operate with a full load discharge pressure of 100 psig and an unload discharge pressure of 110 psig or higher. The actual pressure requirements of painting machinery and tools are often 80 to 90 psig or lower. Reducing and controlling system pressure downstream of the primary receiver can reduce energy consumption, leakage, demand for new capacity, and reduce stress on components and operating equipment.

For their HVAC systems, in addition to installing VFDs, the paint facilities can reduce their energy use by turning off a portion of their equipment when not actively painting. This will allow them to meet the indoor air requirements for painting while at the same time reducing energy consumption. This will also have the effect of reducing the negative pressure experienced by most of the facilities.

As with the metal finishing operations, an area where the Arsenals and Depots could improve their painting facilities is in adopting energy recovery ventilation to recover heat exhausted from the painting spaces before it is vented to the atmosphere. While CCAD cannot take advantage of this opportunity, both RIA and TYAD experience cold winters over relatively long periods of time and so could benefit from this measure.

#### **4.8.8 Areas of Energy Efficient Practices**

For the most part the painting facilities have adopted energy efficient high bay lighting to provide general illumination. This lighting reduces energy use by the facilities and provides the quality light necessary in painting applications.

As with the metal finishing shops, the paint facilities have adopted energy efficient motors in most of their applications. For the most part these motors are sized to fit their applications and have not grown in size as part of routine replacement.

In terms of compressed air, all of the painting facilities have consistently adopted high efficiency equipment and nozzles that allows them to amplify airflow volume while at the same time reducing the amount of air required from the compressors. Additionally, despite the availability of air nozzles and high temperatures both inside and outside the painting spaces, at no time was the use of compressed air for personnel cooling observed. (This practice is not only expensive, but can also be hazardous.)

One striking example of HVAC energy efficient practices observed at all Arsenals and Depots was the consistent changing out of filters when they became clogged or dirty. This action, as part of a proactive maintenance program, ensures that the HVAC systems operate efficiently and provide the space conditioning and outside air required for personnel and to meet indoor air quality requirements.

## **5 Conclusions and Recommendations**

### **5.1 Conclusions**

This work has introduced an ERDC-CERL developed methodology for process energy optimization assessments, and demonstrated it through showcase assessments at selected Army Depots and Arsenal (Rock Island Arsenal, Corpus Christie AD, Tobyhanna AD, Sierra AD, and the Naval Aviation Depot, San Diego), and has identified and summarized energy conservation, industrial process, and environmental opportunities that can significantly improve Army installation mission readiness and competitive position in four specific Army industrial processes: (1) metal casting, (2) metal finishing, (3) painting, and (4) heat treat.

This work compared and benchmarked industrial process energy intensities in these facilities among the assessed military installations and against similar private sector manufacturing facilities. The results of this benchmarking process were used to identify opportunities to improve energy and process efficiencies, and to reduce the environmental impacts of Army industrial activities.

The foundry at Rock Island Arsenal was found to be one of the most energy efficient facilities surveyed as part of this study. The energy density per ton for the process of metal casting at that location was the second smallest of the 59 facilities analyzed.

Metal finishing, painting and heat treat processes at the Arsenals and Depots and at their private industry counterparts, are complex processes; quantitative comparisons are difficult. In general, No one Arsenal or Depot was found to have an overall program either superior or inferior to that of any of the other facilities, or to any of their private industry counterparts. These processes at Army Arsenals and Depots generally operate similarly to those of their private industry counterparts—conscientiously and with dues consideration for operational energy efficiency.



## 5.2 Recommendations

*1. Consider energy efficiency in future decisions regarding equipment upgrades.* To maintain its energy efficiency, the RIA foundry should consider energy efficiency when making future decisions regarding upgrading its equipment. Specific items to consider in upgrading its induction furnaces are static frequency converters, which will match the current or voltage to the type and amount of metal being melted, and molten metal blanketing, a technique that prevents oxidation and gas pickup by molten metals by displacing the atmospheric oxygen and water vapor with a dry and inert atmosphere composed of argon or nitrogen. Both of these technologies have been introduced commercially and will reduce energy consumption per ton of melt.

*2. Perform regular maintenance.* One area where the Arsenals and Depots have an advantage over their private counterparts is in maintenance. Performing often overlooked, regular maintenance comprises a low-risk, low-tech solution that maximizes production reliability and minimizes production interruption, both of which contribute to energy efficiency. Maintenance is, in fact, a profit center that generates production capacity and reduces energy consumption per unit of measure or production.

Over the last several years anecdotal evidence indicates that private industry has been scaling back the number of personnel assigned to maintenance. The same anecdotal evidence indicates that Arsenals and Depots have kept the same numbers of maintenance personnel. This is not to say that some functions have not been outsourced, but overall while the Arsenals and Depots may have redirected the maintenance personnel, the overall numbers and quality of maintenance have remained the same. This has allowed Arsenals and Depots to keep their equipment in such a condition that increases its energy efficiency as compared to similar equipment operated in the same manner by private industrial firms. The Arsenals and Depots should continue this practice.

*3. Match equipment operation with production processes.* Although the assessed facilities are each doing well in reducing energy use, but more can be done. Turning off equipment when processes are not operating, or operating at a partial capacity and adjusting HVAC equipment operation accordingly. These operations (and others) at the Arsenals and Depots use

significant amounts of energy to ventilate their spaces, both in terms of heating air (steam systems, burners, induction elements) and circulating it (fans with large drive motors both pushing and pulling air). In some cases, HVAC equipment (lighting, motors, HVAC equipment, fans, and pumps) can be turned off when particular operations are down due to breaks, or scheduled or unscheduled maintenance. In other cases, where HVAC equipment cannot be completely shut down due to environmental and safety considerations, it can be operated at partial capacity to meet the lower demands, while at the same time reducing energy use. Changing the operation of this equipment may require installation of additional controls, or (for motors) installation of variable frequency drives.

*4. Continue and expand the use of life cycle cost (LCC) analyses in HVAC equipment purchasing.* Arsenals and Depots enjoy an advantage over their commercial counterparts in HVAC equipment purchasing. Industrial facilities commonly use first cost as the deciding factor in equipment purchases considerations. Arsenals and Depots, on the other hand, often use life cycle costing (LCC) analyses to determine all the costs associated with an asset, including acquisition, installation, operation, maintenance, refurbishment, and disposal costs. This allows the Army facilities to implicitly consider energy use and ease of maintenance when making purchasing decisions, both of which contribute to energy efficiency. Use of LCC should be continued and expanded where it serves the Army's purposes to do so. Other relevant factors to consider before replacing existing HVAC equipment would be changes in production processes and newer manufacturing equipment installed that could result in reduced loads on HVAC systems, and a consequent re-evaluation of loads.

*5. Continue to use energy savings performance contracts (ESPCs) to finance capital upgrades with energy conservation components.* Arsenals and Depots should continue to use ESPCs to finance capital upgrades with energy conservation components. ESPCs, while available to private industrial firms, have not gained much acceptance as they have from institutions. ESPCs have been widely adopted by Arsenals and Depots, especially for implementation of lighting projects, which usually have a high capital cost and longer implementation than other energy conservation projects. Working collaboratively, the National Association of Energy Service Companies (NAESCO) and Lawrence Berkeley National Laboratory (LBNL), have built a database currently comprising approximately 1,500 operating

projects. A study of this database concludes that actual energy savings of comprehensive projects consistently exceeded savings predictions - in 69 percent of the cases for lighting and non lighting retrofits and 79 percent of non lighting only retrofits. In lighting only projects, energy service companies (ESCOs) were within 5 percent of their savings estimates in over 50 percent of the projects. The researchers state that actual energy savings are more likely to exceed predictions in these projects and the customer will typically enjoy savings beyond the ESCO's projections. The Arsenals and Depots should continue to take advantage of energy saving performance contracting offered by qualified and experienced ESCOs.

*6. Broaden the use of energy management controls.* Army Arsenals and Depots further pursue energy efficiency by using energy management controls. These control systems use a combination of advanced metering hardware and software to monitor a facility's electricity use, identify inefficiencies, and pinpoint potential threats to reliability. This type of system can provide Arsenal and Depot management and operators with the information to make informed decisions, from both a functional perspective and a financial one. On the functional side, plant operators can efficiently monitor power quality and energy use in real time to increase productivity, improve efficiency, and maintain reliability. On the business side, managers can review the historical consumption data provided to predict energy use for the month, allocate costs by department, and identify waste. A detailed understanding of the facility's energy requirements over time can also help both operators and/or managers to spot recurring trends and increase energy efficiency.

## Appendix A: Thermal Environment Evaluation for Industrial Facilities

The main purpose for heating and air conditioning of work spaces is to provide an environment that is acceptable and does not impair the health and performance of the occupants. During production processes, it may be necessary to work in uncomfortable conditions for a limited time period. Still, these conditions must not be allowed to impair employees' health. Light, noise, air quality and the thermal environment are all factors that will influence the acceptability and performance of the occupants. The recommendations and evaluation methods presented here are based on international recognized standards and guidelines. Several standards dealing with methods for the evaluation of the thermal environment have been published by international standard organizations like International Organization for Standardization (ISO), the European Committee for Standardization (Comité Européen de Normalisation [CEN]), and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

Several of these standards may be used as a basis for the design and evaluation of buildings, HVAC (heating, ventilation and air conditioning) systems, protective equipment (clothing) and optimization of work-rest schedules. The results presented here covers environmental conditions ranging from cold over moderate to hot thermal environments.

Tables A1 and A2 list the results of calculated criteria determined by Dr. Bjarne Olesen (Department of Mechanical Engineering, Technical University of Denmark (DTU), Denmark) for the space temperature for specific activities. This analysis makes the following assumptions:

- *Activity Level.* Activity levels are based on tables from ISO 8996. Specifically, a time study of the actual activity must be made capable of predicting a 1-hour average.
- *Clothing.* Light workshop clothing has been used. The difference between summer and winter is only a piece of underwear.
- *Air Velocity.* Due to the increased activity the relative air velocity around the body will also increase relative to the activity level. In sum-

mer time, a further increase in air velocity from fans and open doors and windows will reduce the heat load so that higher space temperatures may be accepted.

- *Relative Humidity (RH)*. RH has been set to 40 percent for winter and 60 for summer. For hot summer days this may be on the low side.
- Predicted Mean Vote (PMV)–PPD (Predicted Percentage of Dissatisfied) criteria. The recommended temperatures for different Predicted Mean Vote (PMV) values have been calculated. For nonindustrial work it is normally accepted to use  $-0.5 < \text{PMV} < +0.5$ . This is also the criteria used in ASHRAE Standard 55-2004. Since an industrial workplace normally has a relatively selective population (no elderly, children etc.) it may be acceptable to increase the criteria to 1 or maybe 1.5 on the PMV scale. Therefore recommended temperatures also for  $\text{PMV} \pm 1$  are shown.

**Table A1. Summer space temperature criteria for specific activities.**

Work place	Activity level		Summer												
			Clothing	Relative Humidity	Relative air velocity $V_{ar} = 0.3 \text{ (M-1)}$	Operative temperature for PMV=-0.5		Optimal Operative temperature for PMV=0		Operative temperature for PMV=+0.5		Operative temperature for PMV=+1.0		WBGT limit un-acclimatized	
	W/m <sup>2</sup>	met	clo	%	m/s	°C	F	°C	°F	°C	°F	°C	°F	°C	°F
Assembly	81	1.4	0.6	60	0.12	20.3	69	22.4	72	24.5	76	26,6	80	29	84
Maintenance	99	1.7	0.7	60	0.21	17.2	63	19.8	68	22.4	72	25,4	78	29	84
Machining	99	1.7	0.7	60	0.21	17.2	63	19.8	68	22.4	72	25,4	78	29	84
Welding	99	1.7	0.7	60	0.21	17.2	63	19.8	68	22.4	72	25,4	78	29	84
Painting	163	2.8	0.7	60	0.54	12.2	54	15.0	59	17.8	64	20.6	69	26	79
Metal casting	128	2.2	0.7	60	0.36	15.2	59	18.0	64	20.8	69	23.4	74	29	84
Foundry	192	3.3	0.7	60	0.69	10.0	50	12.7	55	15.3	60	18	64	26	79
Woodworking	140	2.4	0.7	60	0.42	14.1	57	16.9	62	19.7	67	22.5	73	26	79
Heat treatment	122	2.1	0.7	60	0.33	16.0	61	18.7	66	21.3	70	24	75	29	84
Soldering	122	2.1	0.7	60	0.33	16.0	61	18.7	66	21.3	70	24	75	29	84

**Table A2. Winter space temperature criteria for specific activities.**

Work place	Activity level		Winter			Operative temperature for PMV= -1.0		Operative temperature for PMV=-0.5		Optimal Operative temperature for PMV=0		Operative temperature for PMV=+0.5		Minimum Operative Temperature for continues work (Ireq-low strain level) Co
			Clothing	Relative Humidity	Relative air velocity var = 0.3 (M-1)									
	W/m2	met	clo	%	m/s	°C	°F	°C	°F	°C	°F	°C	°F	
Assembly	81	1.4	1	40	0.12	14.6	58	17.3	63	20.1	68	22.8	73	10 (0.2 hours)
Maintenance	99	1.7	0.8	40	0.21	14.5	58	17.3	63	20.1	68	22.8	73	10 ( 0.7 hours)
Machining	99	1.7	0.8	40	0.21	14.5	58	17.3	63	20.1	68	22.8	73	10 ( 0.7 hours)
Welding	99	1.7	0.8	40	0.21	14.5	58	17.3	63	20.1	68	22.8	73	10 ( 0.7 hours)
Painting	163	2.8	0.8	40	0.54	<10	<50	11	52	14.2	57	17.3	63	10
Metal casting	128	2.2	0.8	40	0.36	11.2	52	14.3	58	17.4	63	20.4	69	
Foundry	192	3.3	0.8	40	0.69	<10	<50	10	50	12.3	54	14.5	58	6
Woodworking	140	2.4	0.8	40	0.42	10	50	13.2	56	16.3	61	19.3	67	
Heat treatment	122	2.1	0.8	40	0.33	12.1	54	15.1	59	18.1	65	21.1	70	
Soldering	122	2.1	0.8	40	0.33	12.1	54	15.1	59	18.1	65	21.1	70	

The Wet Bulb Globe Temperature (WBGT) offers a useful first order index of the environmental contribution to heat stress. It is influenced by air temperature, radiant heat, and humidity. WBGT values are calculated using one of the following equations:

With direct exposure to sunlight:

$$\text{WBGT}_{\text{out}} = 0.7 T_{\text{nwb}} + 0.2 T_{\text{g}} + 0.1 T_{\text{db}}$$

Without direct exposure to the sun:

$$\text{WBGT}_{\text{in}} = 0.7 T_{\text{nwb}} + 0.3 T_{\text{g}}$$

where:

$T_{\text{nwb}}$  = natural wet bulb temperature (sometimes called NWB)

$T_{\text{g}}$  = globe temperature (sometimes called GT)

$T_{\text{db}}$  = dry bulb (air) temperature (sometimes called DB)

Because WBGT is only an index of the environment, the screen criteria are adjusted for the contributions of work demands and clothing as well as state of acclimatization. Table A3 provides ACGIH (American Conference of Governmental Industrial Hygienists) rest-work guidelines for hot-humid climates. It provides screening criteria for heat stress exposure (WBGT values in °F).

**Table A3. ACGIH rest-work guidelines for hot-humid climates**

Work Demands	Acclimatized Employee		Unacclimatized Employee	
	Light (°F)	Moderate (°F)	Light (°F)	Moderate (°F)
100% Work 0% Rest	85.1	81.5	81.5	77
75% Work 25% Rest	86.9	83.3	84.2	79.7
50% Work 50% Rest	88.7	85.1	86	82.4
25% Work 75% Rest	90.5	87.8	87.8	84.2



## Appendix B: Characteristics of Vehicle Exhaust Systems

### Exhaust characteristics for M1 and M60 Tanks

#### M1A1

Configuration and size:

- center grill 25.24-in. length X 13.21-in. height (Figure B1)
- side cooler grills 27.5-in. length X 13.59-in. height
- 2<sup>nd</sup> side cooler 18.75-in. length X 13.59-in. height.

Exhaust Volume and Temperature:

- tank moving about 5 mph around maintenance area will have 5 lb/sec (3270 CFM) at a temperature of 980 °F.



**Figure B1. M1A1 Tank exhaust.**

The M1 Abrams Tank has a Lycoming Textron gas turbine engine AGT-1500, 1500 HP Combat load less kits:

- gross weight 68.7 tons;
- fuel: DF-2, JP-8, VV-F-800, Mil-DTL-83133
- fuel capacity: M1A1 504.4 gal., M1A2 SEP 445.5 gal
- engine oil 17 qt
- Exhaust located in the rear of the tank between the two hub sprocket carriers with center grille 25.24-in. L x 13.21-in. H, side cooler grilles 27.5-in. L x 13.59-in. H, second side cooler 18.75" L x 13.59" H

### Exhaust volume and temperature:

- Exit of main exhaust grille doors: 12.5 pounds/second (pps) @ 870°F
- Exit of left powerpack cooler: 13 pps @ 249°F
- Exit of right powerpack cooler: 12.3 pps @ 228°F
- Total 37.8 pps (1 exhaust air + 2 cooling air),  $T_{mix} = 477.8^{\circ}\text{F}$
- Tank moving at 5 mph will have 5 pps (7900 cfm) @ 590°F

### M60 Tank (Figure B2)



**Figure B2. M60 Tank with 750 HP Diesel engine, 1021°F exhaust.**

### Exhaust volume and temperature:

- Exit of left exhaust grille: 1.13 pounds/second (pps) @ 882°F
- Exit of center cooler: 22 pps @ 250°F
- Exit of right exhaust grille: 1.13 pps @ 882°F
- Total 24.3 pps (1 exhaust air + 9 cooling air),  $T_{mix} = 308.3^{\circ}\text{F}$

Exhaust Temperature (°F)						
M1		Recuperator	at Grille	1ft from grille	4ft from grille	8 ft from grille
Idle		500	440	420	388	248
Tactical	Idle	600	480	470	432	277
Stall		968	870	818	698	491
M60	Turbo Dis-charge	Exhaust Outlet	at Grille	1ft from grille	4ft from grille	8 ft from grille
Idle	197	186	130	125	107	98
Stall	1021	882	330	196	169	123

## M1 Grille Modification

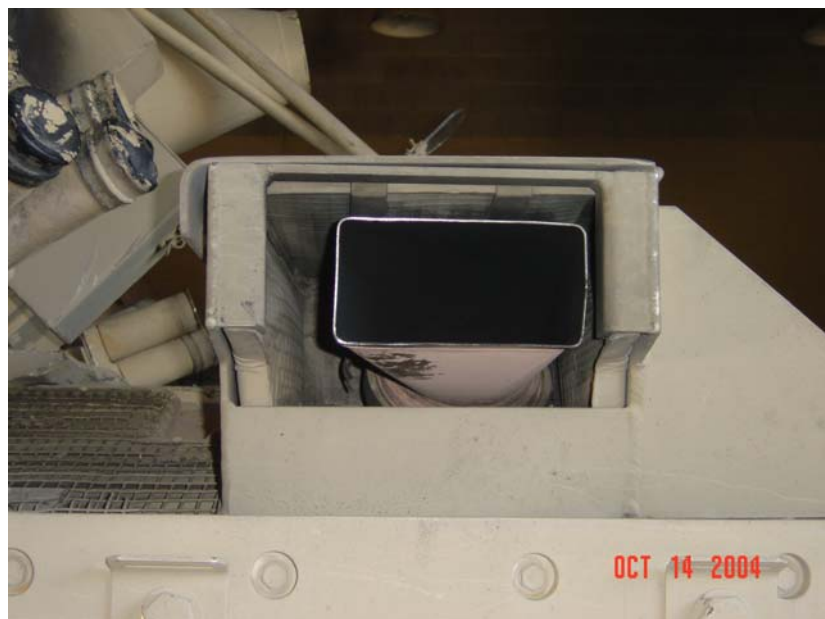
A more rapid reduction of the M1 exhaust temperature profile can be achieved by directing the powerpack cooler air flow to converge with the exhaust at a closer distance behind the vehicle than the current production grille permit. Love converge was achieved by rotating the transmission cooler grilles 45°, doubling the length of the fins and setting the fins at an angle that would improve the converge resulting from the 45° rotation.

Exhaust Temperature (°F above ambient)						
M1	Original	Recuperator	at Grille	1ft from grille	4ft from grille	8 ft from grille
Tactical	Idle	540	421	410	372	217
Stall		908	752	752	633	622
M1	Modified	Recuperator	at Grille	1ft from grille	4ft from grille	8 ft from grille
Tactical	Idle	540	421	387	348	134
Stall		908	752	740	622	324

Source: Exhaust Temperature Comparison of a M60 Tank and M1 with Standard and Modified Rear Grilles, by G.E. Psaros and J.F. Wohler, June 7, 1982, General Dynamics Land Systems Division, Center Line, MI.

## M2A3 and M3A3 Bradley Fighting Vehicles

Specifications: 33 tons, 35 mph max., 600 HP Cummins VTA-903T water-cooled 4-cycle diesel, 903 cu in (14.8 L) engine displacement, exhaust 980 °F at peak torque, flow 3270 cfm max. and 1440 cfm idle. Figure B3 shows the Bradley fighting vehicle exhaust.



**Figure B3. Bradley fighting vehicle exhaust.**

### Stryker Idle Exhaust

Per GDLS-C, the exhaust gas temperature from the engine idling at 1500 RPM leaving the vehicle is 200°F or less at 600 scfm. An adapter that provides an interface with the (Marine Corp) LAV III, will work on the Stryker. GDLS uses this exhaust adapter without removing any vehicle parts such as the engine compartment grill.

### M113 Family of Vehicles (FOV)

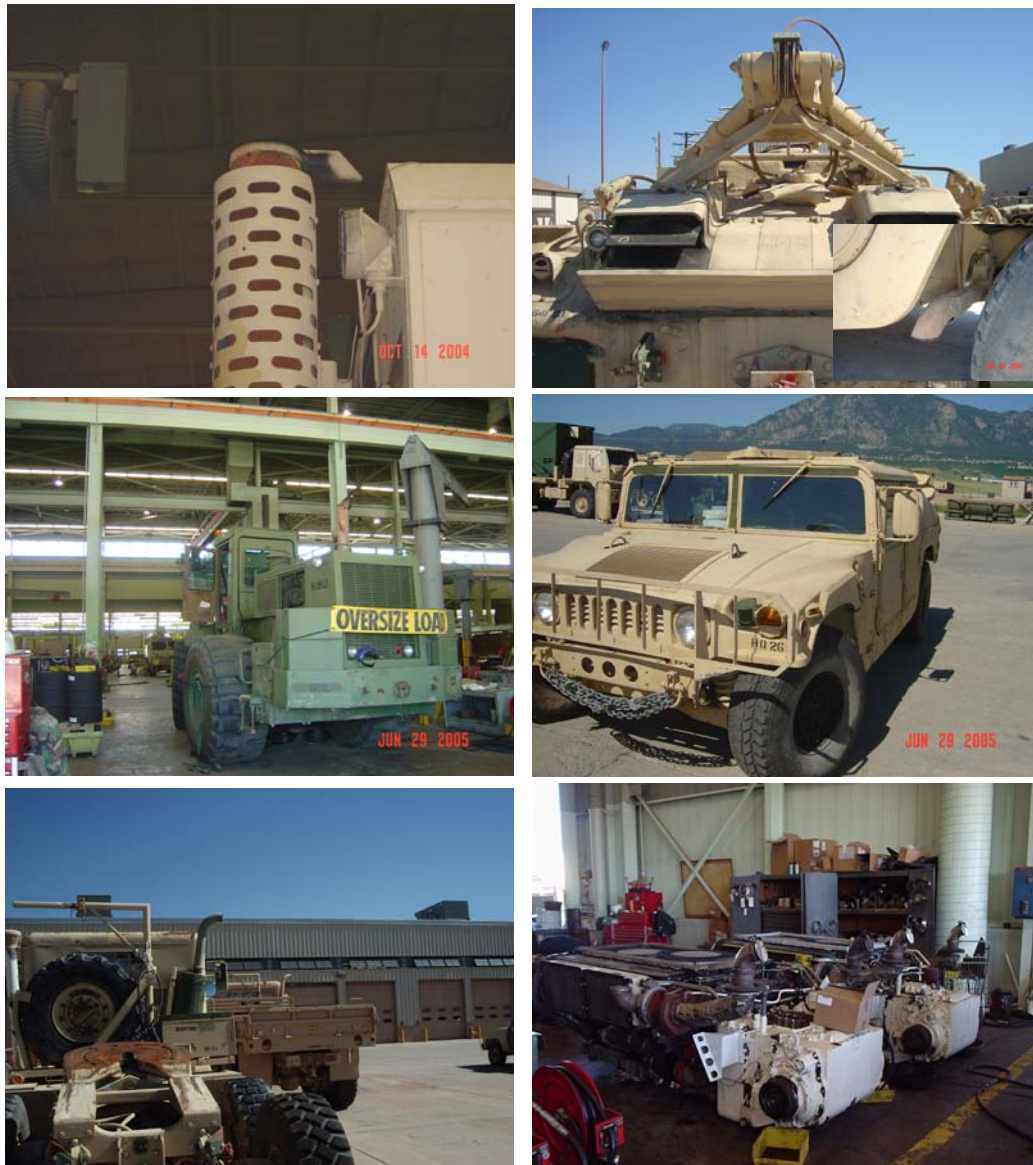
Models: M113, M1064, M1068, M577, M58, M1059, OSV

Exhaust info:

- located right front corner of vehicle
- 5-in. diameter pipe with flapper (see attached dwg)
- exhaust volume: 2190 cfm
- exhaust temp: 680 deg F
- Paladin FAASV
- Model: M109A6 M992A2
- Engine Detroit Diesel 8V71T, 2 cycle, Turbo Charged, Liquid cooled, gross HP 450 at 2300 rpm
- Exhaust location: right, forward of cab, above sponson; oval shape exhaust duct
- Exhaust temperature: Idle: 275 - 375 °F; 5 mph: 775 - 825 °F.

Figure B4 shows some typical military vehicle exhausts.

Vehicle	Application	Exhaust Flow (ft <sup>3</sup> /min)	Exhaust Temperature
HEMTT DDEC IV	8083-7K92	2970	680 deg. F
HEMTT MUI	8083-7493	3070	695 deg. F
PLS & HET	8087-7K91	3330	695 deg. F
M113 A1 or A2	5063-5299	1660	860 deg. F
M113 A3	5063-539L	2210	680 deg. F
M109 Paladin	7083-7391	3210	770 deg. F



**Figure B4. Some typical military vehicle exhausts.**

### **Vehicle exhaust ventilation systems**

Vehicle exhaust ventilation system can mitigate and reduce exposure to Diesel and gasoline fumes generated by moving vehicles. Vehicle exhaust ventilation systems can be adopted to specific conditions of the maintenance facility (e.g., maintenance bay, drive-through corridor) and allow a range of exhausted air volume and withstand temperature ranges specific to variety of vehicles/tactical equipment serviced or repaired in these facilities (figures B5–B7). For the biggest vehicles the military needs to service, exhaust flow varies from 1700 to 3300cfm at temperatures of 650 up to 1200°F (Figure B8).



# STR – Straight Rail Systems

STR is the preferred system for drive through apparatus bays

The STR is the solution for drive-through bays or when vehicles are parked in tandem. The standard design of the STR will allow you to park up to four vehicles in the same bay.



The PlymoVent STR system is designed to connect to any motor vehicle tailpipe and capture 100% of the exhaust emissions. This system is ideal for drive through bays or bays where vehicles are parked in tandem. Everything is automatic from the fan activation to the release from the existing vehicle. All that's required is the simple one step connection to the vehicle's tailpipe when entering quarters.

## Key system advantages

- Models to handle up to 150 ft.
- Exhaust hose sizes for all vehicle types
- Auto-disconnect at exit door
- Door-to-door removal of harmful emissions
- Speed absorbing shock system
- Front and rear door release
- Expandable design
- The system will allow up to four vehicles in tandem
- Adjustable release points depending on the speed of the call-out release
- Automatic start-stop of fan by an exhaust sensor
- 100% Source Capture through a unique pneumatic Grabber, to suit different sizes of exhaust pipes
- Pre-fitted yellow/black extraction hose
- Safety disconnect coupling; Fail safe system, easily reconnectable
- Suitable for existing fire stations and new design build stations



**Figure B5. Product brochure for Plymovent “Straight Rail Systems.”**

Note: Product brochures used with permission of PlymoVent Corp., 115 Melrich Road, Cranbury, New Jersey 08512.

# SBT – Sliding Balancer Track Systems

SBT is the preferred system for back in apparatus bays.

The SBT has set the standard in vehicle emissions control for fire and emergency response vehicles around the world.



The SBT is best suited for vehicles that back-in to an apparatus bay and respond out the same door. If you are looking for an exhaust removal system, that you can connect at the door before backing in and have it automatically disconnect when you leave. The SBT is right for your application.

## Key system advantages



- Models to handle up to 40 ft deep back-in bays
- Auto-disconnect at the exit door
- Attach the Grabber from the vertical position
- No minimum exit speed
- Aluminium track: Light weight and strong
- End stops with rubber shock absorbers; to take up kinetic energy from trolleys
- Adjustable release points depending on the speed of the vehicle



- Pre-fitted yellow/black extraction hose
- 100% source capture through a unique automatic Grabber nozzle; Available in sizes to fit all emergency response vehicle tailpipe sizes
- Automatic start-stop of fan by exhaust sensor.
- Safety disconnect coupling; Fail safe system, easily reconnectable
- Suitable for existing fire stations and new design build stations

**Figure B6. Product brochure for Plymovent “Sliding Balancer Track Systems.”**



## VSR – Vertical Stack Rail Systems

The vertical stack rail requires no operator intervention

The VSR is the solution for vehicles that have top exhaust and have to move through an apparatus bay.



We recommend the VSR for emergency response vehicles with top exhaust such as airport crash rescue and heavy rescue vehicles. The VSR can be set up for back-in or drive-through configurations. It will also handle multiple vehicles in tandem and can be retrofitted into any length of building.

### Key system advantages

- Floating suspension
  - Adjustable capture stack
  - Fits any vehicle stack
  - One-piece aluminium rail
  - A fully automatic system
  - Expandable system to almost any length
- 
- Adapter cone designed for both empty and loaded vehicles.
  - 12" (in.) lateral movement to either side
  - Flexible duct connection
  - Sealing rubber lips
  - Automatic return to position after lateral movement
  - Security wire, fail safe
  - Suitable for existing fire stations and new design build stations



**Figure B7. Product brochure for Plymovent “Vertical Stack Rail Systems.”**



**a.****b.****c.****d.****e.****f.**

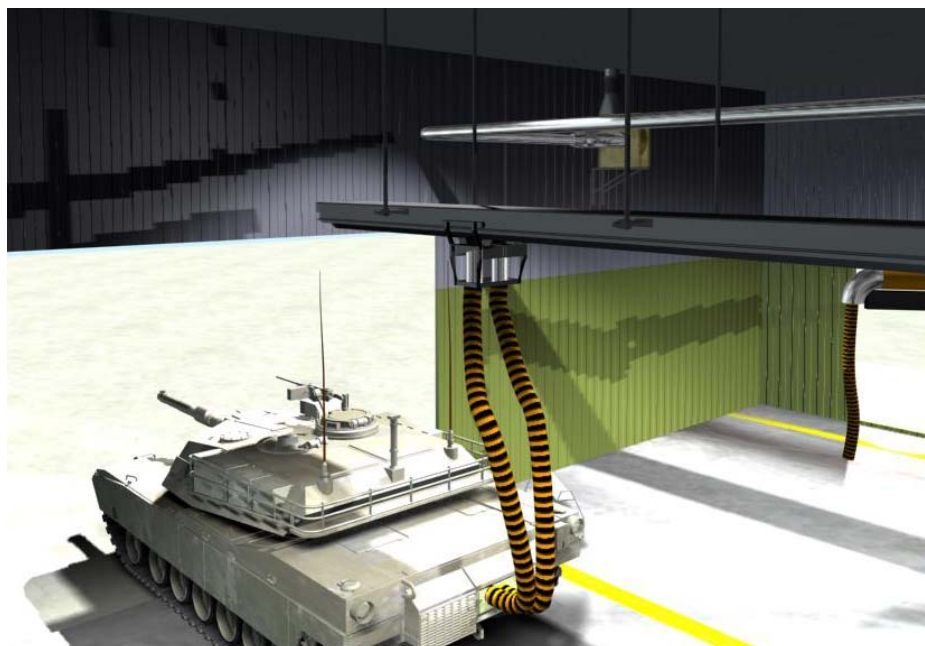
**Figure B8. Examples of mobile vehicle exhaust systems: vehicle exhaust on a boom for a vehicle with a compact tail pipe (a, b, c, d); vehicle exhaust with a compact tail pipe connected to a rail system (e, f).**

Boom Systems 16-ft radius with 6- to 10-in. drops and a Continuous Rail System can be adopted as multifunctional vehicle exhaust systems servicing different types of vehicles. Such a boom system requires two assemblies installed on both sides of the entrance door (Figure B9) to accommodate left or right side tail pipe /vehicle exhaust with the flow rate up to 1700 cfm. A combination of both booms can be used to accommodate A1M1 base vehicles with the exhaust rate up to 4000cfm.



**Figure B9. Boom-based exhaust system allows to capture exhaust fumes from a M1A1 tank moving into and out of the maintenance bay.**

A continuous rail exhaust system (Figure B10) allows capturing of exhaust fumes with a vehicle movement along the preset trajectory (e.g., TEMF central corridor).



**Figure B10. Continuous rail exhaust system.**

Each exhaust system could be equipped with a universal coupling connecting an appropriate connecting nozzle, depending on the type of vehicles to be serviced. Hose sections with nozzles not in use, would be hung at the wall in hose stalls, marked to help operators match up the nozzles appropriately (Figure B11).



**Figure B11. Nozzle designed to accommodate a Bradley-type vehicle.**

The fan for the exhaust system needs to be designed to handle temperatures of between 600 and 1000 degrees. This temperature range will need to be finalized once the fan location is determined so temperature loss can be accounted for and also if one or more exhaust systems are connected to one fan (as in a central exhaust system where one fan serves several bays). Systems designed for vehicles with a high exhaust gas temperatures, shall be equipped with special hoses, which can withstand such temperatures. Regardless if we use one fan per service bay or a central fan it will need to be a belt driven fan with a heat slinger and built to Class B construction standards (at a minimum).

To handle this would require two Boom assemblies, each with 10-in. diameter ductwork and 10-in. flex hose drops. In the upper air volume/temperature range, the 10-in. hose would extend to the nozzle. For lower air volumes/temperatures, a smaller diameter (8- or 6-in. depending on need) hose would be attached to the 10-in. hose through a “universal coupling”. At the tail-pipe end of each hose, a tail pipe specific nozzle would be attached using another “universal coupling”. For each module of the Multi Tasking Vehicle Exhaust System (MTVEX), the different systems’ components are outlined in more detail in Figure B12.

Exhaust systems can have individual fans or be connected to the central exhaust system. For energy efficiency, central exhaust system can be equipped with the demand based control initiated by a pressure sensor in-



stalled inside the individual exhaust ductwork. Central system with the demand control can be sized to exhaust only 30 to 50 percent of the total exhaust rate depending on a particular system. This generally applies to systems with at least three individual exhausts.

## PLYMOVENT<sup>®</sup> EXHAUST GAS TEMPERATURES UP TO +350°F



### EG 350

#### Material

hose wall: neoprene-coated polyester fabric  
external helix: galvanized steel with additional plastic abrasion protector

#### Applications

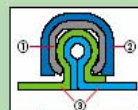
- medium duty exhaust gas extraction from gas or diesel engines
- exhaust gas extraction of engine exhaust gases up to +350°F when exhaust gas funnels are used properly
- all normal exhaust extraction systems such as: hose reel

#### Properties

- vibration proof
- flame resistant, neoprene passed UL 94V-O
- good flow characteristics
- extremely flexible
- compressibility 1:5
- small bend radius
- super lightweight
- extra strength
- special clamping method guarantees high tensile strength between hose material and external helix

#### Construction

- ① external helix
- ② additional abrasion protector
- ③ hose wall: neoprene-coated polyester fabric



#### Temperature Range

- exhaust gas temperatures up to +350°F when exhaust gas funnels are used properly and enough fresh air is utilized

Technical Data, custom designs and forms of delivery see back page

### EG 350

Dia. (in.)	Outer (Dia.)	Negative (in. w.c.)	*Bending radius (in.)	Weight (lbs./ft.)	Product code
3.0	3.56	71	1.84	0.40260	EG-75
4.0	4.68	40	2.40	0.53009	EG-100
5.0	5.68	26	3.00	0.63745	EG-125
6.0	6.68	18	3.60	0.98637	EG-150

\* Referring to the inner side of the elbow of hose.  
The above mentioned data refers to an average and ambient temperature of 68°F. Subject to technical changes and color variations. Please refer to technical data sheet when selecting hose.

#### Delivery forms:

Standard production:

- Dia. 3" - 6"
- Color: black; outer abrasion protector yellow
- Standard lengths 16', 25', 33', 41'

Available on request:

- special lengths: consult Plymovent
- special diameters: consult Plymovent
- fix lengths with mounted bridge clamps

**Figure B12. MTVEX systems components.**

## PLYMOVENT<sup>®</sup> EXHAUST GAS TEMPERATURES UPTO +350°F



### EG 350

#### Material

hose wall: neoprene-coated polyester fabric  
external helix: galvanized steel with additional plastic abrasion protector

#### Applications

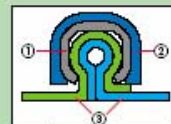
- medium duty exhaust gas extraction from gas or diesel engines
- exhaust gas extraction of engine exhaust gases up to +350°F when exhaust gas funnels are used properly
- all normal exhaust extraction systems such as hose reel

#### Properties

- vibration proof
- flame resistant, neoprene passed UL 94/V-O
- good flow characteristics
- extremely flexible
- compressibility 1:5
- small bend radius
- super lightweight
- extra strength
- special clamping method guarantees high tensile strength between hose material and external helix

#### Construction

- ① external helix
- ② additional abrasion protector
- ③ hose wall: neoprene-coated polyester fabric



#### Temperature Range

- exhaust gas temperatures up to +350°F when exhaust gas funnels are used properly and enough fresh air is utilized

Technical Data, custom designs and forms of delivery see back page

### EG 350

Dia. (in.)	Outer (Dia.)	Negative (in. w.c.)	*Bending radius (in.)	Weight (lbs./ft.)	Product code
3.0	3.56	71	1.84	0.40260	EG-75
4.0	4.68	40	2.40	0.53009	EG-100
5.0	5.68	26	3.00	0.63745	EG-125
6.0	6.68	18	3.60	0.98637	EG-150

\* Referring to the inner side of the elbow of hose.

The above mentioned data refers to an average and ambient temperature of 68°F. Subject to technical changes and color variations. Please refer to technical data sheet when selecting hose.

#### Delivery forms:

Standard production:

- Dia. 3" - 6"
- Color: black
- outer abrasion protector yellow
- Standard lengths 16', 25', 33', 41'

Available on request:

- special lengths: consult Plymovent
- special diameters: consult Plymovent
- fix lengths with mounted bridge clamps

Figure D16. MIVEA systems components.

## PLYMOVENT<sup>®</sup> EXHAUST GAS TEMPERATURES UP TO +570°F



### EF 570

#### Material

hose wall: neoprene-coated polyester fabric  
external helix: galvanized steel with additional plastic abrasion protector

#### Applications

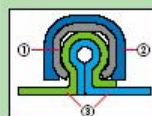
- medium duty exhaust gas extraction from gas or diesel engines
- exhaust gas extraction of engine exhaust gases up to +570°F when exhaust gas funnels are used properly
- all normal exhaust extraction systems such as hose reel

#### Properties

- vibration proof
- flame resistant, neoprene passed UL 94V-O
- good flow characteristics
- extremely flexible
- compressibility 1:5
- small bend radius
- super lightweight
- extra strength
- special clamping method guarantees high tensile strength between hose material and external helix

#### Construction

- ① external helix
- ② additional abrasion protector
- ③ hose wall: neoprene-coated polyester fabric



#### Temperature Range

- exhaust gas temperatures up to +570°F, short times up to +600°F when exhaust gas funnels are used properly and enough fresh air is utilized

Technical Data, custom designs and forms of delivery see back page

### EF 570

Dia. (in.)	Outer (Dia.)	Negative (in. w.c.)	*Bending radius (in.)	Weight (lbs./ft.)	Product code
3.0	3.56	56	1.84	0.32879	EF-75
4.0	4.68	32	2.40	0.42944	EF-100
5.0	5.68	20	3.00	0.53009	EF-125
6.0	6.68	14	3.60	0.82533	EF-150

\* Referring to the inner side of the elbow of hose.

The above mentioned data refers to an average and ambient temperature of 68°F. Subject to technical changes and color variations. Please refer to technical data sheet when selecting hose.

#### Delivery forms:

##### Standard production:

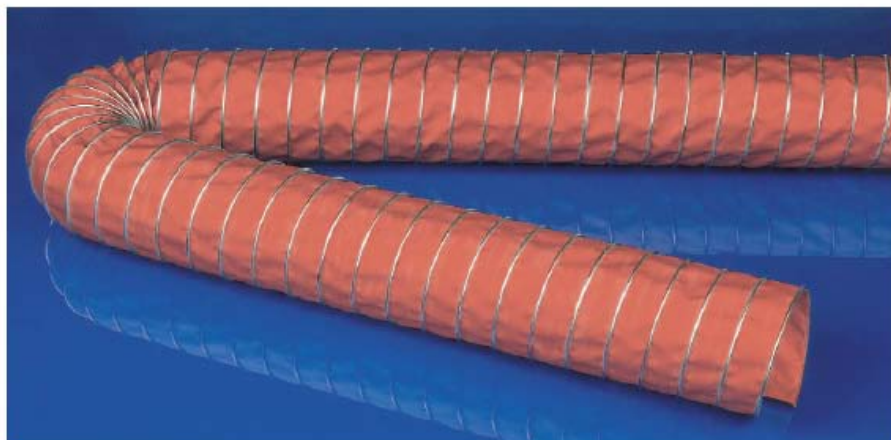
- Dia. 3" - 6"
- Color: black  
outer abrasion protector yellow
- Standard lengths 16', 25', 33', 41'

##### Available on request:

- special lengths: consult Plymovent
- special diameters: consult Plymovent
- fix lengths with mounted bridge clamps

**Figure B12. (Cont'd).**

## PLYMOVENT<sup>®</sup> EXHAUST GAS TEMPERATURES UP TO +850°F



### HT 850

#### Material

hose wall: high temperature silicon coated glass fabric, asbestos free  
external helix: galvanized helix  
Also available in stainless steel

#### Applications

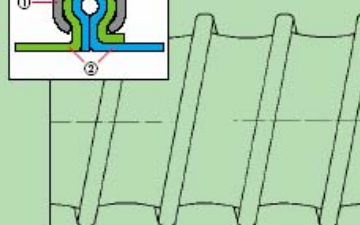
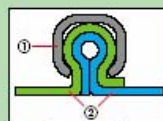
- vehicle exhaust systems
- high temp diesel exhaust
- engine construction
- all usual suction extraction systems such as hose reel

#### Properties

- very high temperature resistance
- highly flexible
- extreme compressibility 1:6
- small bend radius
- improved vacuum resistance
- external steel helix protects against abrasion
- suitable for continually flexing
- does not emit airborne fibers
- special damping method guarantees high tensile strength between hose, material and external helix

#### Construction

- ① external helix
- ② hose wall: high temperature silicon fabric



#### Temperature Range

- -5°F up to +850°F
- intermittent to +950°F when exhaust gas funnels are used properly and enough fresh air is utilized

Technical Data, custom designs and forms of delivery see back page

### HT 850

Dia (in.)	Positive (in. w.c.)	Negative (in. w.c.)	*Bending radius (in.)	Outer Dia (in.)	Weight (lbs./ft.)	Product code
4.0	121	35	2.40	0.70	0.23485	71 0042
5.0	84	22	3.00	0.90	0.30866	71 0043
6.0	63	16	3.60	1.20	0.32879	71 0044
7.0	49	12	4.20	1.30	0.35563	71 0045
8.0	40	9	4.80	1.40	0.39589	71 0046

\* Referring to the inner side of the elbow of hose.

The above mentioned data refers to an average and ambient temperature of 68°F. Subject to technical changes and color variations. Please refer to technical data sheet when selecting hose.

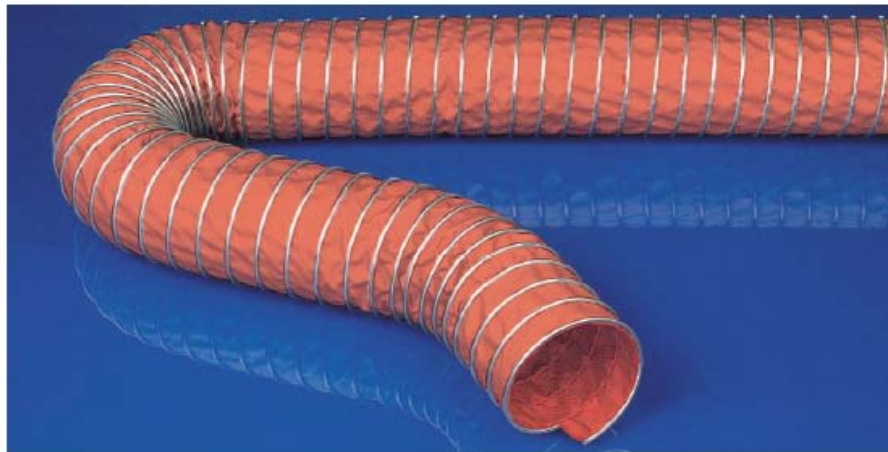
#### Delivery forms:

- Standard production:
- Other diameters available
  - Color: orange
  - 10' or longer
- Available on request:
- special lengths: consult Plymovent
  - external helix also in stainless steel

**Figure B12. (Cont'd).**



## PLYMOVENT<sup>®</sup> EXHAUST GAS TEMPERATURES UP TO +1200



### ET 1200

#### Material

hose wall: two-layer construction, inner and outer hose wall asbestos free high-temperature fabric, specially coated with heat-stabilizers, reinforced by woven in stainless steel wire  
external helix: galvanized steel

#### Applications

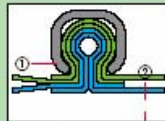
- exhaust-fume extraction from high performance test beds in the motor vehicle industries
- vehicle and engine construction
- dynamometer
- aircraft and defense industries
- general engineering

#### Properties

- very high temperature resistance
- flame resistant
- improved vibration resistance by woven-in reinforcement
- flexible, compressibility 1:3
- small bend radius
- good vacuum-resistance
- silicone free
- external steel helix protects against abrasion
- special damping method guarantees high tensile strength between hose material and external helix

#### Construction

- ① external helix
- ② hose wall
- ③ outside and inside: special-coated high temperature fabric



#### Temperature Range

- -75°F up to +1200°F
- intermittent to +1380°F

small amounts of smoke maybe given off when used under positive pressure or with low extraction rates

Technical Data, custom designs and forms of delivery see back page

### ET 1200

Dia. (in.)	Positive (in. w.c.)	Negative (in. w.c.)	*Bending radius (in.)	Weight (lbs./ft.)	Product code
3.0	201	102	1.80	1.10715	ET-75
4.0	141	67	2.40	1.20780	ET-100
5.0	109	42	3.00	1.40910	ET-125
6.0	69	30	3.60	1.47620	ET-150
8.0	49	17	5.60	2.01300	ET-200

\* Referring to the inner side of the elbow of hose.

The above mentioned data refers to an average and ambient temperature of 68°F. Subject to technical changes and color variations. Please refer to technical data sheet when selecting hose.

#### Delivery forms:

- Standard production:
- Dia. 3" - 8"
  - Color: red
  - Production lengths 16', 25', 33', 41'

Available on request:

- special lengths: consult Plymovent
- special diameters: consult Plymovent
- external helix also in stainless steel

Figure B12. (Cont'd).



## PLYMOVENT<sup>®</sup> EXHAUST GAS TEMPERATURES UPTO +2010°F



### HT 2010

#### Material

hose wall: three-layer construction, asbestos-free, high-temperature fabric, special coated with heat-stabilizers  
external helix: stainless steel

#### Applications

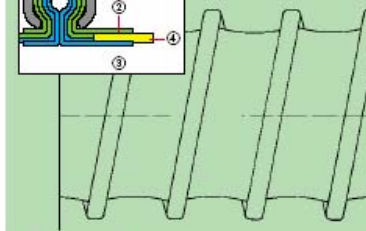
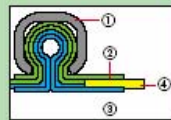
- extremely high temperatures
- exhaust-fume extraction from large engines
- vehicle and engine construction
- aircraft and defense industries
- general engineering
- exhaust-fume extraction from high performance test beds in the motor vehicle industries
- extraction of aircraft engine fumes
- dynamometer

#### Properties

- very high temperature resistance
- flame resistant
- silicone free
- flexible; compressibility 1:2
- small bend radius
- external steel helix protects against abrasion
- special clamping method guarantees high tensile strength between hose material and external helix

#### Construction

- ① external helix
- hose wall:
- ② outside and ③ inside and
- ④ middle layer: special-coated high temperature fabric



#### Temperature Range

- -75°F up to +2010°F
- intermittent to +2370°F

small amounts of smoke maybe given off when used under positive pressure or with low extraction rates.

Technical Data, custom designs and forms of delivery see back page

### HT 2010

Dia. (in.)	Positive (in. w.c.)	Negative (in. w.c.)	*Bending radius (in.)	Weight (lbs./ft.)	Product code
6.0	69	37	3.60	1.1407	710070
7.0	59	27	4.20	1.3420	710071
8.0	49	20	5.60	1.4762	710072

\* Referring to the inner side of the elbow of hose.

The above mentioned data refers to an average and ambient temperature of 68°F. Subject to technical changes and color variations. Please refer to technical data sheet when selecting hose.

#### Delivery forms:

Standard production:

- Dia. 6" - 8"
- Color: outside red
- Production lengths consult Plymovent

Available on request:

- special lengths: consult Plymovent
- special diameters: consult Plymovent

**Figure B12. (Cont'd).**

## Appendix C: Q&A on Army Painting Systems Efficiency Improvement and Energy Use Reduction

### What is the optimum drying temperature?

**MIL-P-53022B:** The epoxy primer will air dry at temperatures above 70°F. Its dry slows dramatically at temperatures below that and essentially stops altogether below about 50 °F

**MIL-C-46168:** Will air dry at almost any temperature above freezing.

**MIL-C-53039:** Will dry at temperatures above freezing, also. It will be limited by the water carrying capacity of the air, which limits the absolute humidity (not relative humidity) and consequently will not dry well below 50 °F.

**MIL-PRF-64159:** Lower temperatures mean that the air is easily saturated with moisture, even when there isn't that much absolute water in the air. Temperatures below 50 °F will inhibit the release of water from the coating film and should be avoided.

### Will increasing temperature speed drying time?

**MIL-P-53022B:** Generally, higher temp equals faster dry. Too high a temperature for too long may produce a primed surface that must be sanded before topcoating, however.

**MIL-C-46168:** Generally, higher temp equals faster dry.

**MIL-C-53039:** Because of the moisture curing characteristic of this product, temperatures above 180 °F will not produce faster drying and may slow down the cure, due to lack of moisture in the hot air of the oven.

**MIL-PRF-64159:** This product has excess isocyanate content in common with MIL-C-53039. Consequently it acts like a moisture cured coating. Temperatures above 180 °F will not produce faster drying and may slow down the cure, due to lack of moisture in the hot air of the oven.

### Is humidity important to drying?

**MIL-P-53022B:** Too much humidity will inhibit dry (above 90 percent) due to slower solvent evaporation.

**MIL-C-46168:** Too much humidity will inhibit dry (above 90 percent) due to slower solvent evaporation.

**MIL-C-53039:** Too much humidity will inhibit dry (above 90 percent) due to slower solvent evaporation. Too little humidity (below 10 percent) will speed up the flash off (apparent dry), but inhibit curing due to slow moisture curing.

**MIL-PRF-64159:** Too much humidity will inhibit dry (above 85 percent) due to slower water evaporation. Too little humidity (below 10 percent) will speed up the flash off (apparent dry), but inhibit curing due to slow moisture curing.

### Is convection or radiant drying better?

This answer is case specific but in general radiant heat is more efficient than convection with painted objects of regular shape. Flat stock is particularly successful with radiant (IR) cure. Large or irregularly shaped objects will be better served with convection curing.

### What is the optimum flash-off temperature?

The optimum temperature for each coating is 77 °F is; the optimum range is 70 – 80°F.

### Will increasing temperature speed flash-off time?

Yes, but temperatures exceeding 100 °F degrees during flash off may cause blistering or other defects in the coating.

### Is humidity important to flash-off?

Yes. As in #3 (above), if the solvent release from the film is inhibited, high humidity can produce a result similar to having no flash off at all (blisters and other film defects).

### What is the optimum Painting temperature?

The optimum temperature is 77 °F; the optimum range is 70 – 80 °F (the same as #5).

### What is the optimum curing temperature?

This will vary based on the production line and its constraints. If we could ask for a specific cure schedule, it would be a 15-minute flash off followed by a force cure of 30 minutes at 140 to 180 °F. This would serve each type well.

### How dry does primer need to be painting topcoat?

“Wet on wet” topcoat on primer application is discouraged. There is a lot of evidence that this procedure will lead to premature performance failure of the coating system, despite an apparently good finish from an aesthetic standpoint. MIL-DTL-53072 (the Chemical Agent Resistant Coating [CARC] painting process specification) recommends a minimum of 5 hours dry before topcoating.

### Does paint present a VOC problem in regards to air pollution?

**MIL-P-53022B:** Type I is high in VOC content, Type II is below 3.5 lbs/gal (420 gm/L).

**MIL-C-46168:** Type II is high in VOC content; Type IV is below 3.5 lbs/gal (420 gm/L).

**Mil-C-53039:** All products under this spec are below 3.5 lbs/gal (420 gm/L) in VOC Content.

**MIL-PRF-64159:** Both Type I and Type II are below 1.8 lbs/gal (220 gm/L) in VOC content.

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